GEOLOGICAL SURVEY OF CANADA
BULLETIN 572

LITHOSTRATIGRAPHY, SEDIMENTOLOGY, PALEONTOLOGY, ORGANIC PETROLOGY, AND ORGANIC GEOCHEMISTRY OF THE MIDDLE DEVONIAN ASHERN, WINNIPEGOSIS, AND EYOT FORMATIONS IN EAST-CENTRAL ALBERTA AND WEST-CENTRAL SASKATCHEWAN

N.C. Meijer Drees, G.S. Nowlan, M.G. Fowler, L.D. Stasiuk,
D.C. McGregor, B.R. Palmer, and G.D. Addison

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Cover Illustration
Top of Winnipegosis at Killam 16-10-46-13W4 (depth 1592.5 m). Silty dolostone, including halite-filled fenestral vugs, Charophyte oogonia and dark bituminous shale interbeds is overlain by a modular mixture of light grey halite and brown dolomitic anhydrite (GSC photo no. 4413-6).

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LITHOSTRATIGRAPHY, SEDIMENTOLOGY, PALEONTOLOGY, ORGANIC PETROLOGY, AND ORGANIC GEOCHEMISTRY OF THE MIDDLE DEVONIAN ASHERN, WINNIPEGOSIS, AND EYOT FORMATIONS IN EAST-CENTRAL ALBERTA AND WEST-CENTRAL SASKATCHEWAN

Abstract

The Middle Devonian succession in the subsurface of east-central Alberta and west-central Saskatchewan unconformably overlies Cambrian and Ordovician strata. It locally onlaps the Red River subcrop ridge along the Ordovician subcrop edge, which extends into west-central Saskatchewan as the Meadow Lake Escarpment. The succession includes the basal transgressive clastic rocks of the Ashern Formation, overlain by a shelf-like wedge of carbonate deposits that forms the Winnipegosis Formation. The Winnipegosis Formation increases in thickness to the east and is in lateral contact with the lower part of the Prairie evaporite deposits of west-central Saskatchewan. In central Alberta the upper part of the Prairie evaporite deposits overlies the Winnipegosis Formation and changes laterally into dolomitic shale and siltstone of the newly proposed Eyot Formation.

Because the informal subdivision in the basinal part of the Winnipegosis Formation in Manitoba and Saskatchewan is not useful in the marginal part of west-central Alberta, four new members are introduced in Alberta. In ascending order they are the Eyehill, Cutknife, Killam, and Bawif. The Eyehill Member is in mappable continuity with the lower Winnipegosis member of southern Saskatchewan and extends westward into east-central Alberta. The Cutknife is in mappable continuity with the upper Winnipegosis member of southwestern Saskatchewan and extends westward beyond the depositional limit of the Eyehill. In west-central Saskatchewan both the Killam and the Bawif members are in lateral facies contact with the upper part of the Shell Lake Member of the Prairie Formation. They extend westward into east-central Alberta beyond the depositional limit of the Eyehill Formation.

Thin carbonaceous and bituminous shale interbeds are present in the clastic and shelf carbonate deposits. Carbonaceous shale contains up to 54% total organic carbon (TOC), and hydrogen indices (HI) range between 170 and 367 mg hydrocarbons (HC) per gram (g) TOC. Bituminous shale contains up to 12% TOC and HI range up to 744 mg HC/g TOC. Organic-rich units in the lower part of the Ashern Formation include organic matter derived from land plants, while those in the upper part also include organic material derived from marine organisms. The carbonaceous material in beds associated with marginal-marine and marine carbonate of the Winnipegosis contains mostly Type III kerogen, and that in the anhydritic carbonate includes Type II and Type III kerogens.

Several of the carbonaceous shale samples yielded well-preserved spores and other microfossils. Spores diagnostic of the Givetian Stage were obtained from the Ashern, Winnipegosis, and Eyot formations. The Cutknife Member includes *Stringocephalus* brachiopods, also diagnostic for the Givetian.

Résumé

La succession du Dévonien moyen en subsurface dans le centre est de l'Alberta et le centre ouest de la Saskatchewan repose en discordance sur des strates cambriennes et ordoviciennes. Par endroits, elle forme un biseau d'aggradation sur la crête enfouie de la Formation de Red River le long de la bordure ordovicienne enfouie, qui constitue l'escarpement de Meadow Lake et s'étend jusque dans le centre ouest de la Saskatchewan. La succession comprend les roches clastiques transgressives basales de la Formation d'Ashern, sur lesquelles repose un biseau de roches carbonatées ressemblant à une plate-forme qui constitue la Formation de Winnipegosis. La Formation de Winnepegosis s'épaissit vers l'est et est en contact latéral avec la partie inférieure des évaporites de la Formation de Prairie du centre ouest de la Saskatchewan. Dans le centre de l'Alberta, la partie supérieure de ces évaporites repose sur la Formation de Winnipegosis et passe latéralement au shale dolomitique et au siltstone de la Formation d'Eyot nouvellement proposée.

Comme la subdivision informelle des roches de bassin de la Formation de Winnipegosis au Manitoba et en Saskatchewan ne peut être appliquée aux roches de la succession marginale dans le centre est de l'Alberta, quatre nouveaux membres ont été établis en Alberta. Il s'agit, en ordre ascendant, des membres d'Eyehill, de Cutknife, de Killam et de Bawif. Le Membre d'Eyehill prolonge le membre inférieur de la Formation de Winnipegosis du sud

de la Saskatchewan et s'étend vers l'ouest jusque dans le centre est de l'Alberta. Le Membre de Cutknife prolonge le membre supérieur de la Formation de Winnipegosis du sud-ouest de la Saskatchewan et s'étend vers l'ouest jusqu'au-delà de la limite de dépôt du Membre d'Eyehill. Dans le centre ouest de la Saskatchewan, les membres de Killam et de Bawif sont en contact latéral avec la partie supérieure du Membre de Shell Lake de la Formation de Prairie. Ils se prolongent vers l'ouest jusque dans le centre est de l'Alberta, au-delà de la limite de dépôt du Membre d'Eyehill.

Les roches clastiques et carbonatées de plate-forme contiennent de minces interstratifications de shale charbonneux et de shale bitumineux. Le shale charbonneux peut contenir jusqu'à 54 % de carbone organique total et l'indice d'hydrogène se situe entre 170 et 367 mg d'hydrocarbures par gramme de carbone organique total. Le shale bitumineux peut contenir jusqu'à 12 % de carbone organique total et l'indice d'hydrogène atteint jusqu'à 744 mg d'hydrocarbures par gramme de carbone organique total. La matière organique des unités de la partie inférieure de la Formation d'Ashern provient en partie de plantes terrestres, tandis que celle des unités de la partie supérieure provient aussi en partie d'organismes marins. La matière charbonneuse dans les lits associés aux roches carbonatées marines et margino-marines de la Formation de Winnipegosis contient surtout du kérogène de type III, tandis que celle des roches carbonatées à anhydrite contient du kérogène des types II et III.

Plusieurs échantillons de shale charbonneux contenaient des spores et d'autres microfossiles bien préservés. Les formations d'Ashern, de Winnipegosis et d'Eyot ont fournit des spores caractéristiques du Givétien. Le Membre de Cutknife a donné des brachiopodes *Stringocephalus*, également caractéristiques du Givétien.

Summary

The Middle Devonian Ashern, Winnipegosis, and Eyot formations belong to the upper part of the Elk Point Group. In Alberta they form a wedge of interbedded clastic and carbonate rocks that fringes the Western Alberta Ridge. In east-central Alberta they onlap a ridge along the subcrop edge of the Ordovician Red River Formation. This subcrop ridge continues northeastward into west-central Saskatchewan as the Meadow Lake Escarpment. The stratigraphy of the marginal, onlap succession is different from that of the basinal succession in southern Saskatchewan and the outcrop succession in Manitoba.

In east-central Alberta the Ashern Formation forms a marginal, basal transgressive deposit and includes a regolith-like breccia and a dolomitic siltstone unit. The overlying Winnipegosis Formation is a carbonate wedge composed of slope and shelf carbonates, which increases in thickness to the east and is in lateral contact with the lower part of the Prairie evaporite deposits of west-central Saskatchewan.

Because the top of the Winnipegosis in Alberta was defined at a higher stratigraphic level than in Saskatchewan and the succession in the carbonate wedge is dominated by stratigraphic onlap, it is not possible to use the subdivision established in Saskatchewan. Thus it is proposed here to subdivide the Winnipegosis of east-central Alberta into the Eyehill, Cutknife, Killam, and Bawif members.

The Eyehill Member overlies the Ashern and correlates with the lower member of the Winnipegosis Formation of south-central Saskatchewan. The Cutknife Member is in mappable continuity with the upper member of the Winnipegosis Formation of southwestern Saskatchewan. It extends westward beyond the depositional limit of the Eyehill. The Killam and Bawif members are in mappable continuity with the upper part of the Shell Lake Member of the Prairie Formation. The Killam Member does not reach across the Ordovician subcrop ridge because it is truncated by the Bawif Member.

The partly dolomitized, shaly and locally crinoidal wackestone facies of the Eyehill Member decreases in thickness toward the west and grades into the siltstone deposits of the Ashern Formation.

The Cutknife Member consists of a lower, nodular-bedded, in part dolomitized, crinoidal wackestone facies, with corals, brachiopods, and bulbous stromatoporoids, and an upper, dolomitized, peloidal pack- to grainstone facies including a variety of stromatoporoids.

The Killam Member, composed of thin-bedded and laminated, peloidal and anhydritic dolostone, includes interbeds of nodular anhydrite.

The Bawif Member is composed of interbedded dolomitic siltstone and silty and anhydritic dolostone, which includes interbeds of nodular anhydrite.

In east-central Alberta the carbonate wedge of the Winnipegosis Formation is overlain by salt deposits of the Prairie Formation. These deposits change westward into the Eyot Formation, an interbedded succession of dolomitic siltstone, shale, argillaceous dolostone, and anhydritic dolostone. This facies change lies at some distance west of the Ordovician subcrop ridge and marks the lateral transition between the Eyot Formation and the Bawif Member of the Winnipegosis Formation.

Thin carbonaceous and bituminous shale interbeds are present in the clastic rocks and shelf carbonate. Carbonaceous shale contains up to 54% total organic carbon (TOC), and hydrogen indices (HI) range between 170 and 367 mg hydrocarbons (HC) per gram (g) TOC. Bituminous shale contains up to 12% TOC and HI range up to 744 mg HC/g TOC.

Results from geochemical, micropaleontological and organic-petrological analyses indicate that the carbonaceous and bituminous shale beds in the lower part of the Ashern Formation include organic matter derived from land plants, while those in the upper part also include organic material derived from marine organisms. Shale partings of the Cutknife and Killam contain a mixture of algae, plant spores, and marine micro-organisms; those of the Bawif Member and Eyot Formation contain terrestrial plant material and algae.

Sedimentary structures suggest that the Cutknife Member is a marine deposit, with the lower part representing an environment of deposition below average wave-induced turbulence. The upper part represents a shallow-water environment dominated by waves and currents. The Killam Member includes structures typical of supratidal and evaporitic conditions. Sedimentary structures characteristic of alternating dry and wet, evaporitic conditions are present in the Bawif Member. They are commonly deformed by nodular growth of anhydrite and halite crystals.

A sample of the Bawif Member from the regolith-like breccia on the crest of the Ordovician subcrop ridge yielded a remarkably diverse reworked conodont fauna, including species representative of several Early Ordovician stages. A Middle Devonian spore assemblage was obtained from the Ashern Formation. Givetian spores were recovered from the Winnipegosis and Eyot formations.

Sommaire

Les formations d'Ashern, de Winnipegosis et d'Eyot du Dévonien moyen appartiennent à la partie supérieure du Groupe d'Elk Point. En Alberta, elles forment un biseau de roches clastiques et carbonatées interstratifiées en bordure de la crête d'Alberta Ouest. Dans le centre est de la province, elles forment un biseau d'aggradation sur une crête le long de la bordure enfouie de la Formation de Red River de l'Ordovicien. Cette crête enfouie constitue l'escarpement de Meadow Lake et se prolonge vers le nord-est jusque dans le centre ouest de la Saskatchewan. La stratigraphie de la succession marginale d'aggradation est différente de celle de la succession de bassin dans le sud de la Saskatchewan et de la succession de la zone d'affleurement au Manitoba.

Dans le centre est de l'Alberta, la Formation d'Ashern constitue un dépôt transgressif basal marginal et comprend notamment une brèche d'aspect régolithique et une unité de siltstone dolomitique. La Formation de Winnipegosis sus-jacente forme un biseau composé de roches carbonatées de talus et de plate-forme qui s'épaissit vers l'est et qui est en contact latéral avec la partie inférieure des évaporites de la Formation de Prairie du centre ouest de la Saskatchewan.

Comme le sommet de la Formation de Winnipegosis a été établi à un niveau stratigraphique plus élevé en Alberta qu'en Saskatchewan et comme l'aggradation prédomine dans le biseau de roches carbonatées, il est impossible d'utiliser les subdivisions établies pour la Saskatchewan. Nous proposons donc, dans cet article, de subdiviser la Formation de Winnipegosis du centre est de l'Alberta en quatre membres, soit ceux d'Eyehill, de Cutknife, de Killam et de Bawif.

Le Membre d'Eyehill repose sur la Formation d'Ashern et est mis en corrélation avec le membre inférieur de la Formation de Winnipegosis du centre sud de la Saskatchewan. Le Membre de Cutknife prolonge le membre supérieur de la Formation de Winnipegosis du sud-ouest de la Saskatchewan et s'étend vers l'ouest au-delà de la

limite de dépôt du Membre d'Eyehill. Les membres de Killam et de Bawif prolongent la partie supérieure du Membre de Shell Lake de la Formation de Prairie. Le Membre de Killam ne s'étend pas au-delà de la crête ordovicienne enfouie parce qu'il est tronqué par le Membre de Bawif.

Le faciès de wackestone shaleux, en partie dolomitisé et localement crinoïdal, du Membre d'Eyehill s'amincit vers l'ouest et passe progressivement au siltstone de la Formation d'Ashern.

Le Membre de Cutknife comprend deux faciès : à la base, un faciès de wackestone crinoïdal en partie dolomitisé, en couches noduleuses, renfermant des coraux, des brachiopodes et des stromatoporoïdés bulbeux; au sommet, un faciès dolomitisé allant du packstone au grainstone à pellets et comportant une grande variété de stromatoporoïdés.

Le Membre de Killam se compose de minces couches laminaires de dolomie à pellets et à anhydrite, et comprend des interstratifications à anhydrite noduleuse.

Le Membre de Bawif se compose de siltstone dolomitique et de dolomie silteuse et anhydritique interstratifiés, avec des interstratifications à anhydrite noduleuse.

Dans le centre est de l'Alberta, le biseau de roches carbonatées de la Formation de Winnipegosis est recouvert par des dépôts de sel de la Formation de Prairie. Ces dépôts font place, vers l'ouest, à la Formation d'Eyot, succession de siltstone dolomitique, de shale, de dolomie argileuse et de dolomie anhydritique interstratifiés. Ce changement de faciès survient à quelque distance à l'ouest de la crête ordovicienne enfouie et marque la transition latérale entre la Formation d'Eyot et le Membre de Bawif de la Formation de Winnipegosis.

Les roches carbonatées de plate-forme et les roches clastiques présentent de minces interstratifications de shale bitumeux et de shale charbonneux. Le shale charbonneux peut contenir jusqu'à 54 % de carbone organique total et l'indice d'hydrogène se situe entre 170 et 367 mg d'hydrocarbures par gramme de carbone organique total. Le shale bitumineux peut contenir jusqu'à 12 % de carbone organique total et l'indice d'hydrogène atteint jusqu'à 744 mg hydrocarbures par gramme de carbone organique total.

Les analyses géochimiques, micropaléontologiques et de pétrologie organique indiquent que la matière organique dans les lits de shale charbonneux et de shale bitumineux de la partie inférieure de la Formation d'Ashern provient en partie de plantes terrestres, tandis que celle des lits de la partie supérieure de la formation provient en outre en partie d'organismes marins. Les délits de shale dans les membres de Cutknife et de Killam contiennent un mélange d'algues, de spores de plantes et de micro-organismes marins; ceux dans le membre de Bawif et dans la Formation d'Eyot contiennent des débris de végétaux terrestres et des algues.

Les structures sédimentaires laissent croire que le Membre de Cutknife est un dépôt marin, la partie inférieure du membre s'étant accumulée sous le niveau de turbulence moyenne engendrée par les vagues et la partie supérieure, en eau peu profonde où dominaient les courants et les vagues. Le Membre de Killam comporte des structures caractéristiques des milieux supratidal et évaporitique. Enfin, les structures sédimentaires observées dans le Membre de Bawif présentent des caractéristiques d'alternance entre des milieux évaporitiques secs et humides. Elles sont souvent déformées par des accumulations de nodules d'anhydrite et de cristaux d'halite.

Un échantillon du Membre de Bawif prélevé dans la brèche d'aspect régolithique au sommet de la crête ordovicienne enfouie présente une faune de conodontes remaniée remarquablement variée, dont des espèces caractéristiques de plusieurs étages de l'Ordovicien précoce. Un assemblage de spores du Dévonien moyen a été obtenu dans la Formation d'Ashern et des spores du Givétien ont été trouvées dans les formations de Winnipegosis et d'Eyot.

INTRODUCTION

The discovery of oil in east-central Alberta at Spiers 16-16-34-15W4 and Rich 7-25-34-21W4, in 1985 and 1986, respectively, renewed the interest of the oil industry in Middle Devonian rocks in this region. The many deep wells that were subsequently drilled to test the lower Paleozoic strata have provided new information. This information, in the form of borehole logs, drillstem tests and cores, was studied by the Geological Survey of Canada (GSC) through a project jointly funded by a number of oil companies as part of the Industrial Partners Program.

The purpose of the study was to provide a fresh look at the detailed stratigraphy and to localize, analyze and describe the hydrocarbon-rich deposits and assess their potential as source rocks. The geological and geochemical information obtained for the study was discussed and compiled for the partners in two GSC Open File reports (Nowlan, 1998a, b).

The industrial partners agreed that the scientific information should be used to increase knowledge of the Middle Devonian Elk Point Group geology in the study area (Fig. 1) by means of future publications. Such scientific reports are subject to review. During this process it was recommended that a formal, rather than an informal description of the stratigraphy, be used. The resulting new stratigraphic nomenclature included in this Bulletin has been approved by the GSC Committee on Stratigraphic Nomenclature.

Previous work

The few deep boreholes drilled prior to 1964 in Alberta and Saskatchewan provided enough information for Sandberg and Hammond (1958), Porter and Fuller (1959, 1964), van Hees and North (1964) and Grayston et al. (1964) to establish a geological framework of the lower Paleozoic succession in the prairie provinces. These authors have shown that in the subsurface of east-central Alberta and west-central Saskatchewan (Fig. 1) Devonian strata overlie and onlap a significant, erosional unconformity, which truncates the Ordovician, Silurian and Cambrian rock successions (Fig. 2). They further established a type-section for the lower, mainly evaporitic part of the Devonian succession and introduced subsurface map-units based on a combination of lithological and geophysical borehole characteristics (Fig. 3).

After the initial exploration stage the activity of the oil industry shifted to central and northern Alberta. Lower Paleozoic strata in east-central Alberta and west-central Saskatchewan did not receive much attention until oil was discovered at Rich in 1985. The renewed exploration and drilling activity in east-central Alberta added more geological information to the older database and since 1998 a number of informal GSC and confidential company reports have been generated.

Present work

This report describes the Elk Point Group in the region where McGehee (1949), Crickmay (1954), van Hees (1956), Belyea (1959), Sherwin (1962) and Grayston et al. (1964) established the stratigraphic framework of the Lower to Middle Devonian strata. The subdivision of the Elk Point Group into map units proposed by Grayston et al. (1964) was amended by others (Jones, 1965; Holter, 1969; Douglas et al., 1970; Hamilton, 1971; Reinson and Wardlaw, 1972; Fuzesy, 1980; Meijer Drees, 1985, 1986, 1994; Moore, 1988, 1989, 1993). This established stratigraphy was subsequently adopted by the Alberta Energy Conservation Board (now the Alberta Energy and Utilities Board).

The purpose of this report is to describe the onlap pattern of the Middle Devonian strata in east-central Alberta; to establish the map units used to illustrate the onlap; to show that the succession is distinctly different from that in south-central Saskatchewan; and to integrate and discuss the borehole information obtained from micropaleontological, organic-petrological, geochemical, lithological, and sedimentological studies.

In order to facilitate access to the large amount of geophysical, lithological, and geochemical data obtained from the borehole cores, 17 diagrams were made to integrate the new information. Thirteen are included here; the remaining ones are available in the GSC Open File reports (Nowlan, 1998a, b). This report is based on information available in 1994.

Acknowledgments

Sixteen companies joined the two-year-long project to study the petroleum potential of the lower Paleozoic strata. Amoco Canada Ltd., Cabre Exploration Ltd., Canadian Hunter Exploration Ltd., Chevron Canada Resources, Crestar Energy, Gulf Canada Resources, Home Oil Company, Hunt Oil Company, Husky Oil Operations Ltd., Mobil Oil Canada Ltd., Norcen Energy Resources, Pan Canadian Petroleum, Shell Canada, Suncor, Unocal Canada Exploration, and Wascana Energy made financial and in-kind contributions that were combined with specially allocated funds from the Geological Survey of Canada. G.S. Nowlan acted as project leader and studied the Cambro-Ordovician conodonts. B.R. Palmer culled and manipulated the Alberta Energy Conservation Board well

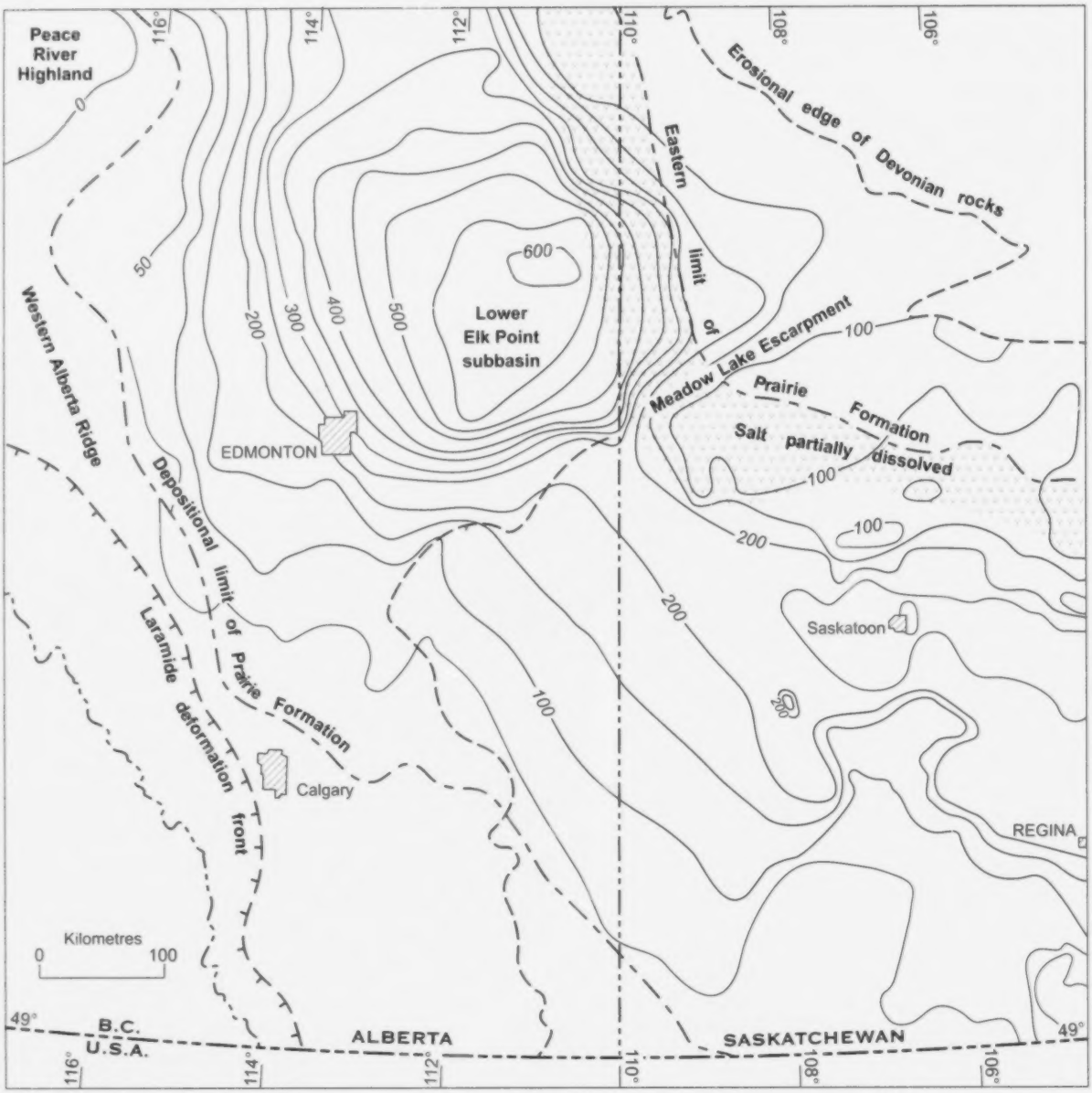


Figure 1. *Isopach map of the Elk Point Group in Alberta and Saskatchewan.*

database and obtained information on the Middle Devonian formations. N.C. Meijer Drees described 614.18 m of Devonian core, polished 99 core samples for photography, collected 540 samples for geochemical analysis and submitted 113 samples for petrographic analysis. G.D. Addison curated the samples. M.G. Fowler and L.D. Stasiuk studied the organic matter in the geochemical samples and D.C. McGregor reported on 64 Devonian samples submitted for palynological analysis, of which 43 contained stratigraphically useful assemblages. The Alberta Energy Control Board granted us permission to take samples from cores stored at the Core Research Centre in Calgary. Without this permission and the help of personnel at the Core Research Centre this study could not have been undertaken. Many people made contributions and deserve to be acknowledged. G. Andrews and L. Breakey made geological compilations during the first phase of the project. R. Wicander (Central Michigan University), T. Uyeno and

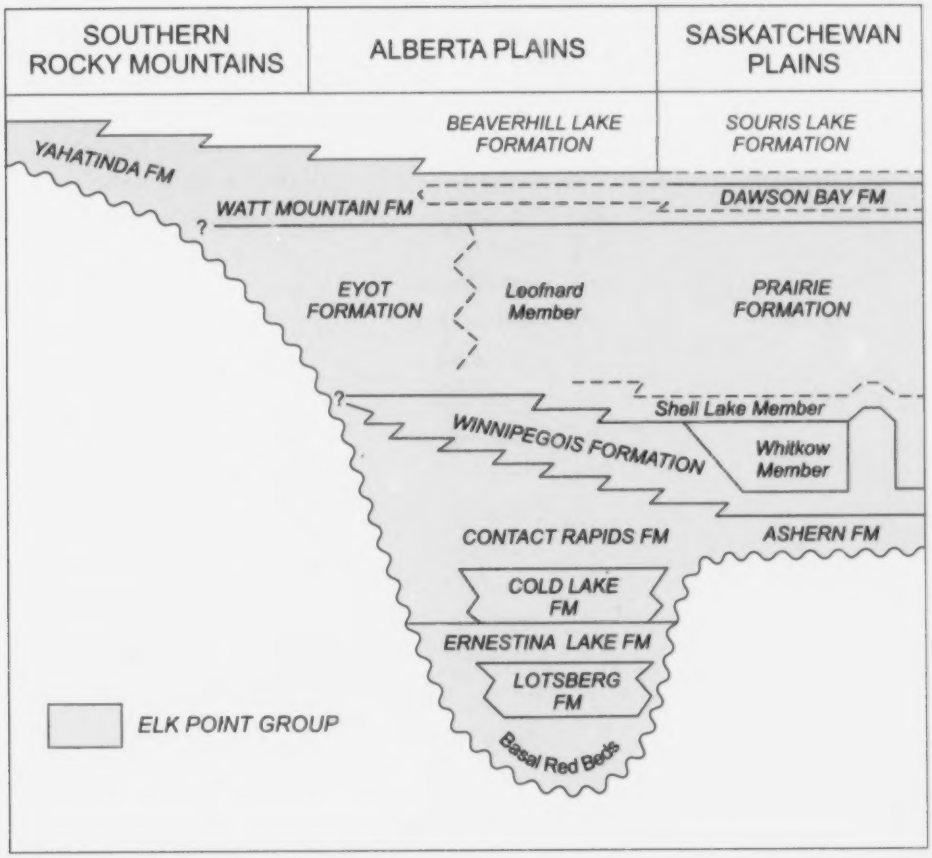


Figure 2. *Stratigraphy of the Elk Point Group in southern Saskatchewan and central Alberta. In Saskatchewan the top of the Dawson Bay Formation marks the upper boundary of the Elk Point Group.*

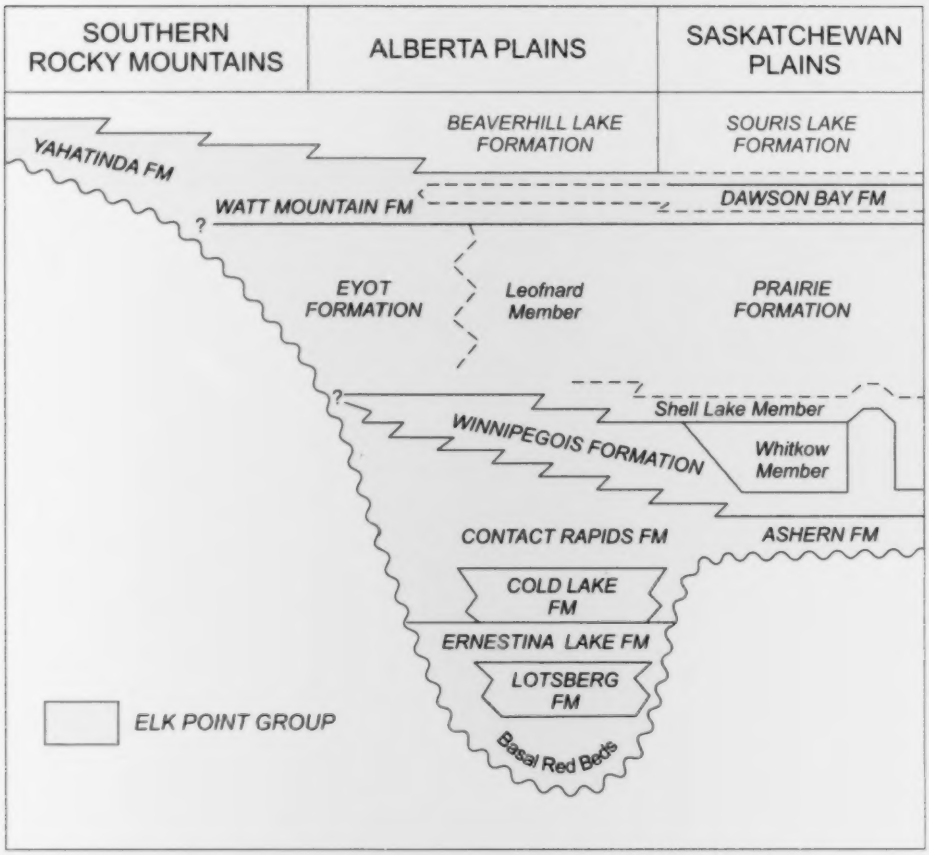
B. Norford (both of the Geological Survey of Canada) submitted paleontological reports. B. Rutley photographed core samples.

The report was reviewed and greatly improved by K.G. Osadetz, A.F. Embry, D.W. Morrow, F. Haidl, and J.P. Zonneveld.

GEOLOGICAL SETTING

The Elk Point Group in east-central Alberta and west-central Saskatchewan (Fig. 2) is an interbedded succession of fine- and coarse-grained clastic rocks, redbed deposits, and evaporite and carbonate deposits that initially accumulated in the Elk Point Basin, a paleotopographic depression centred in east-central Alberta (Grayston et al., 1964). The succession overlies an erosional unconformity that truncates both the Cambrian strata in the Lloydminster Embayment and Ordovician strata at the edge of the Williston Basin. The relief of the pre-Devonian unconformity, measured by means of stratigraphic onlap, is approximately 400 m in central Alberta but exceeds 600 m in western Alberta. The relief is visible on the isopachs of the Elk Point Group (Fig. 1) because the top of the Elk Point succession is a relatively flat surface. The isopachs outline the Central Alberta subbasin, a circular depression in west-central Alberta (Grayston et al., 1964). The more elevated regions surrounding the subbasin were named Saskatchewan Plateau, Western Alberta Ridge, and Peace River Arch. The relatively steep southeastern margin of the central Alberta subbasin in west-central Saskatchewan was named the Meadow Lake Escarpment (van Hees, 1958; Grayston et al., 1964).

The most elevated part of the Meadow Lake Escarpment in west-central Saskatchewan more or less coincides with the subcrop edge of the Upper Ordovician Red River Formation (van Hees, 1958; Fuzesy, 1980), a unit composed of massive carbonate. This carbonate overlies relatively soft



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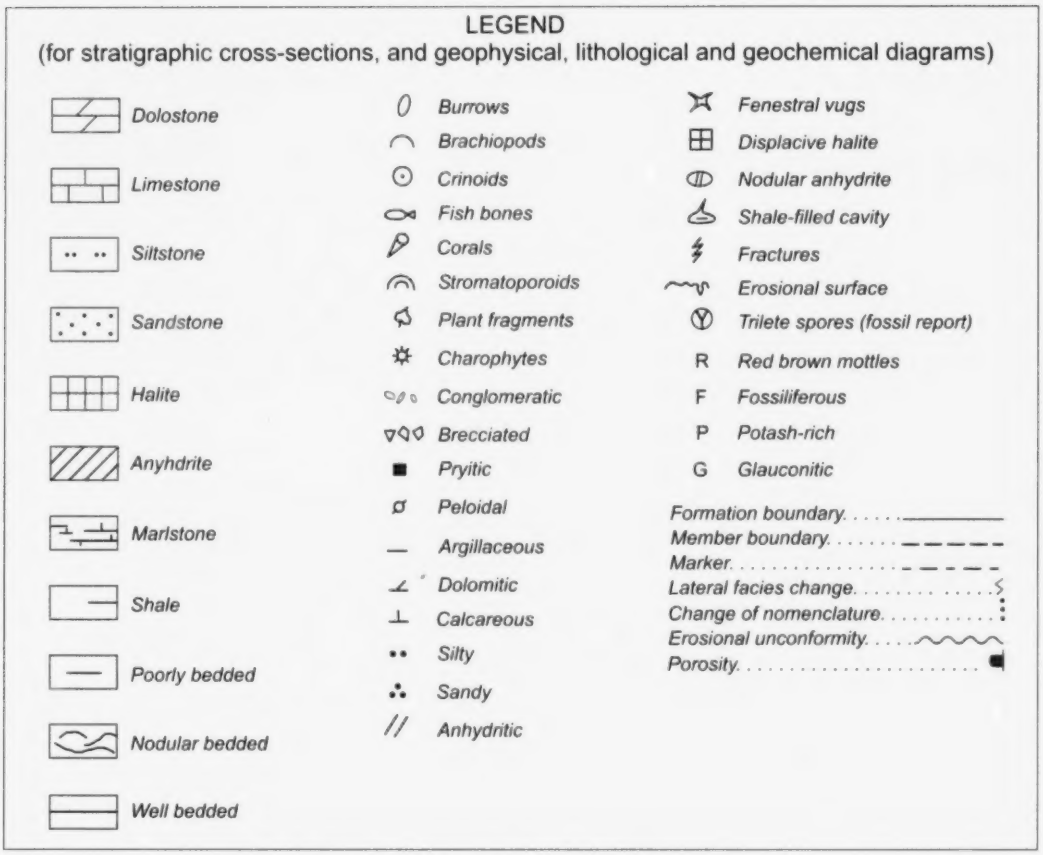


shale of the Deadwood Formation (ranging in age from Middle Cambrian to Lower Ordovician) which forms the lower part of the Escarpment. On the isopach map of the Elk Point strata (Fig. 1) the southwestward trend of the Escarpment into Alberta is recognizable by the closely spaced isopachs east of Edmonton. Here the subcrop edge of the Red River Formation curves south and continues southward toward the Canada-USA border (Norford et al., 1994). It is evident from the spacing of the Elk Point isopach lines that in the region southeast of Edmonton the elevation loss at the southerly trending subcrop edge of the Red River Formation is less significant than that at the northeasterly trending Escarpment.

The relief of the pre-Devonian surface had a major influence on the thickness and distribution of clastic rocks, evaporite, and carbonate in the lower part of the Elk Point Group. The basal sandstone, redbed deposits and associated nonmarine salt deposits in the lower part of the Elk Point Group (Lotsberg Formation) accumulated in the central part of the Central Alberta subbasin (Grayston et al., 1964; Hamilton, 1971; Meijer Drees, 1986). The lower part of the Contact Rapids Formation (Sherwin, 1962) of central Alberta onlaps the Meadow Lake Escarpment in west-central Saskatchewan (van Hees, 1958; Fuzesy, 1980). The upper part continues across the Saskatchewan Plateau in southern Saskatchewan and merges with the Ashern Formation of the Williston Basin (Grayston et al., 1964; Meijer Drees,1986, 1994).

The upper part of the Elk Point Group, described in this paper, is composed of interbedded carbonate, redbed deposits and salt. It overlies redbed units, evaporite, and carbonate of the lower Elk Point subbasin of west-central Alberta and extends southeastward into southern Saskatchewan, Montana, Manitoba, and North Dakota, and northwestward into northern Alberta and the southern Mackenzie District of the Northwest Territories. The northeastern part of this succession is missing (Fig. 1), because of pre-Cretaceous erosion at the top of the Elk Point succession and dissolution of the salt deposits within the succession along the subcrop edge in Alberta, Saskatchewan, and Manitoba (Holter, 1969; Fuzesy, 1980; Meijer Drees, 1986). The upper Elk Point evaporite and clastic rocks change laterally northwestward into marine carbonate (Law, 1955; Klingspor, 1969; Meijer Drees, 1986) suggesting that they accumulated in an embayment that had a northerly connection to the sea (Maiklem, 1971; Williams, 1984; Meijer Drees, 1994).

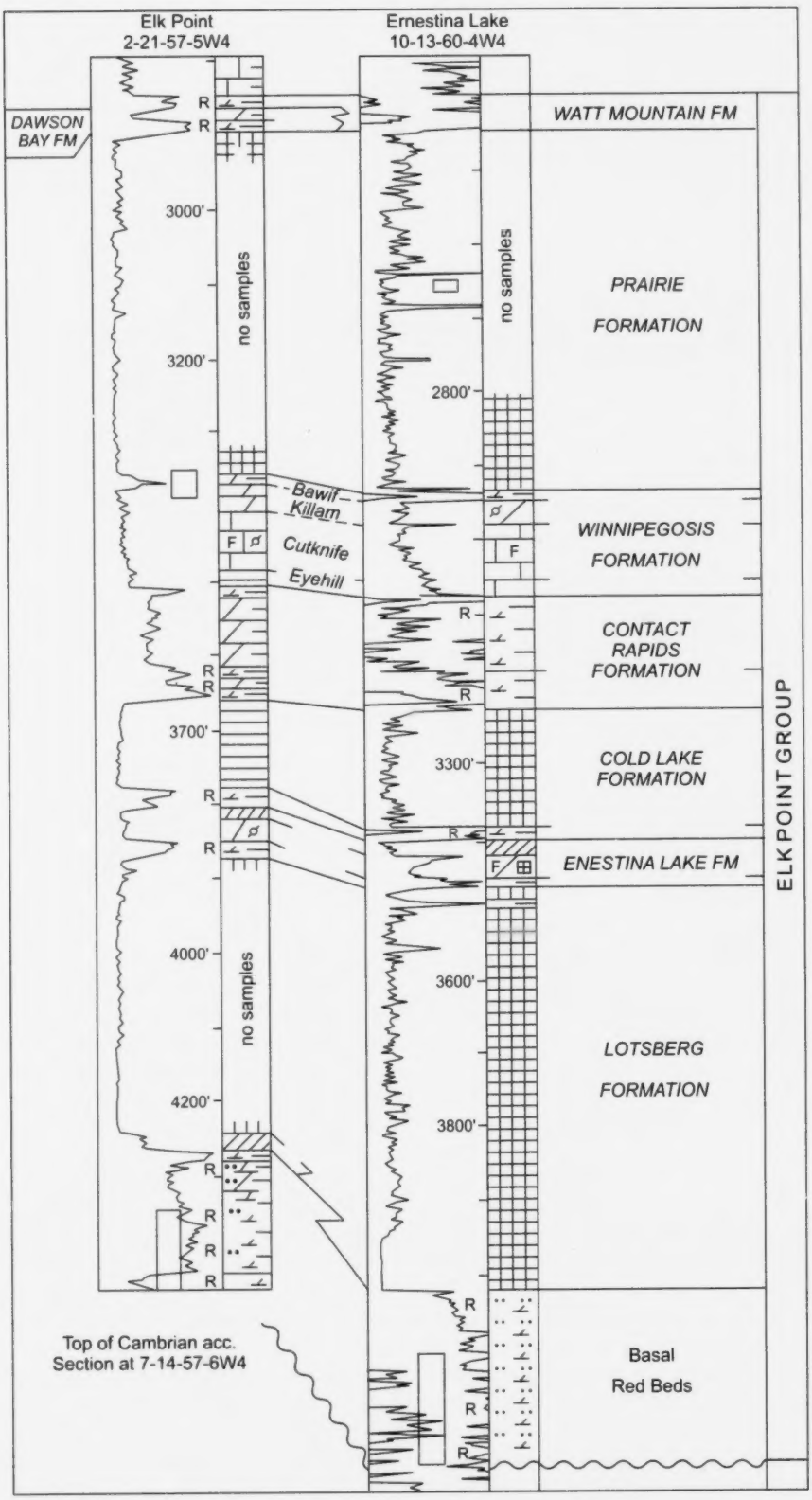


Figure 3. *Type sections of the Elk Point Group and Lower Elk Point formations (modified from Meijer Drees, 1994 and Grayston et al., 1964).*

LITHOSTRATIGRAPHY

Baillie (1953a, b) introduced the first regional stratigraphy of the Devonian rocks in the subsurface of south-central Saskatchewan. Grayston et al. (1964), summarizing the work of others (Crickmay, 1954; Belyea, 1959; Sherwin, 1962; Norris, 1963), established a formal subdivision of the Elk Point Group in the type section of the Anglo-Canadian Elk Point No. 11 borehole, located at 2-21-57-5W4 in Alberta (Fig. 3). Here it includes the Contact Rapids, Winnipegosis and Dawson Bay formations. Subsequently, minor changes in the stratigraphy were made by Jones (1965), Holter (1969), Reinson and Wardlaw (1972), Norris et al. (1982) and Meijer Drees (1986). The units shown in Figure 2 are used at the present time.

In the Paleozoic outcrop region of southeastern Manitoba only the upper part of the Elk Point succession is represented. It includes the Ashern, Elm Point and Winnipegosis formations (Baillie, 1950; Norris et al., 1982). Here the evaporite of the overlying Prairie Formation was dissolved by circulating groundwater from the region southwest of the outcrop and subcrop belts. The dissolution of the salt deposits resulted in fracturing and collapse of the overlying beds and the accumulation of a residual deposit or a collapse breccia (Holter, 1969; Norris et al., 1982; Meijer Drees, 1985).

In east-central Alberta the upper part of the Elk Point Group overlies the Contact Rapids Formation and includes the Winnipegosis, Prairie and Watt Mountain formations. These formations extend to the southwest and onlap the Western Alberta Ridge. The salt deposits of the Prairie Formation change westward into non-evaporitic nearshore deposits, for which the name Eyot Formation is proposed (Fig. 2).

Ashern Formation

The Ashern Formation was defined by Baillie (1950) in the Paleozoic outcrop belt of southwestern Manitoba where it overlies carbonate of Silurian age with an erosional unconformity and locally includes dolostone pebbles derived from the underlying beds (Norris et al., 1982). The formation consists of brick red to greyish orange, silty and argillaceous dolostone and is unconformably overlain by the Elm Point Formation.

Baillie (1953b) introduced the Ashern Formation in the subsurface of southwestern Manitoba and southern Saskatchewan where it is recognizable on borehole logs as a shaly interval in a thick succession of carbonate. In this area it is between 3 and 15.2 m thick and composed of reddish brown, sandy shale, overlain by green or green and reddish brown mottled, dolomitic shale and greenish grey, nodular, argillaceous and, in places, fossiliferous dolostone. The lower contact with the Silurian carbonate of the Interlake Group is an erosional unconformity that locally includes a regolith-like breccia and shale-filled cavities. The upper contact with the Winnipegosis Formation is distinct and is marked by a conglomeratic deposit (Perrin, 1982; Martindale and MacDonald, 1989).

Subdivisions

Walker (1957) divided the Ashern into a lower, reddish brown member and an upper grey member. He mapped the complementary thickness variations of the two members. Jones (1965) described a similar situation in west-central Saskatchewan and showed that the thickness of the formation decreases to the southwest because of onlap against the pre-Devonian unconformity and a lateral facies shift into the lower part of the overlying Winnipegosis carbonate (see also Meijer Drees, 1986, fig. 34).

Meijer Drees (1986, fig. 28, 29) correlated the Ashern Formation on regional cross-sections from southeastern Saskatchewan into east-central Alberta. On these sections the Ashern truncates the underlying strata and onlaps the pre-Devonian unconformity in a northwesterly direction. Thus in east-central Alberta the upper part of the Ashern is in lateral contact with the Winnipegosis Formation. On the crest of the Red River subcrop ridge (Fig. 4) it is replaced by a grey, crinoidal claystone facies that is too thin to form a mappable unit. The facies is included with the Winnipegosis Formation.

Regional distribution

The Ashern Formation is widely distributed in southwestern Manitoba and southern Saskatchewan (Paterson, 1973). In the Tableland region of southeastern Saskatchewan it is 10 to 16 m thick and consists of argillaceous, microcrystalline dolostone (Martindale and MacDonald, 1989). In the Lloydminster area of east-central Saskatchewan the lower part of the Ashern Formation is reddish brown and the upper part is grey. Here the thickness of the formation ranges from 7 to 20 m (Meijer Drees, 1985).

In east-central Alberta, east of the subcrop edge of the Red River Formation, the Ashern Formation is represented solely by the upper grey member. Here it forms a marginal clastic facies that is more or less coeval with the lower part of the Winnipegosis Formation (Fig. 5). It commonly overlies a regolith or rubble-conglomerate that has a greenish grey siltstone or claystone matrix (Plate Ia). In west-central Saskatchewan the claystone matrix is dolomitic and mottled with reddish brown. The thickness of the Ashern Formation decreases westward from 6 m to zero.

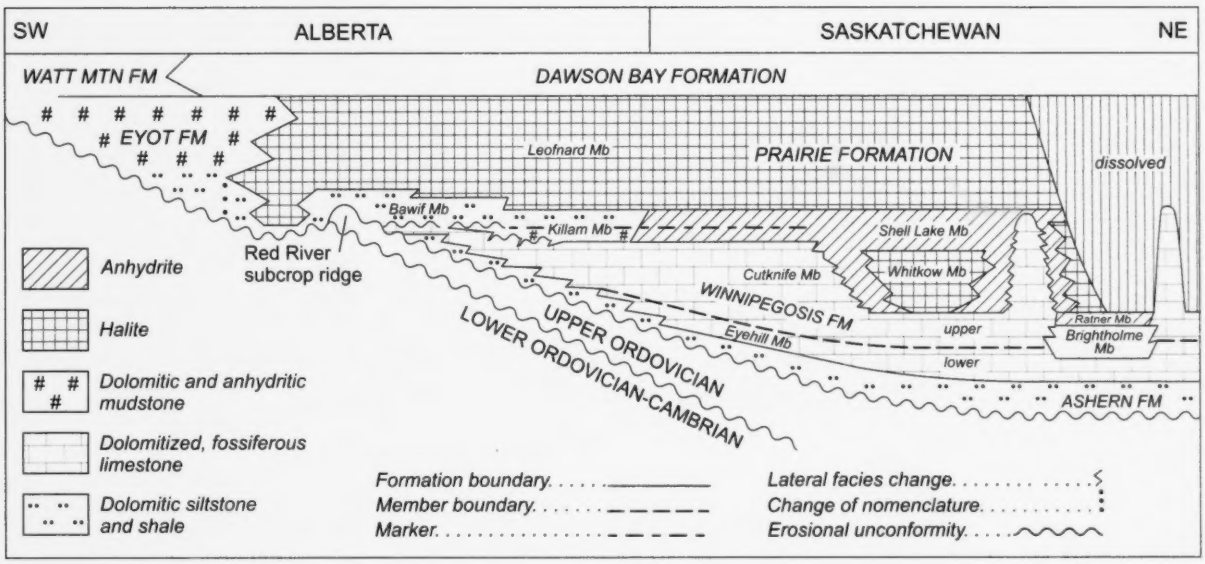


Figure 4. *Schematic cross-section of the pre-Devonian unconformity and the stratigraphy of the Upper Elk Point strata in central Alberta and west-central Saskatchewan.*

In the region northwest of the subcrop edge of the Meadow Lake Escarpment the Ashern Formation merges into the upper part of the Contact Rapids Formation (Fig. 5). Here (e.g., Killam N 16-10-46-13W4) strata equivalent to the Ashern Formation in the upper part of the Contact Rapids Formation are separated from the lower part by an erosional surface overlain by a layer of limestone granules (Fig. 6, depth 1621.83 m).

Lithology

In east-central Alberta, at Eyehill 13-36-35-2W4 and Provost 11-35-38-10W4 (Fig. 7, 8), the Ashern Formation overlies the Red River Formation and is overlain by the lower part of the Winnipegosis Formation. Here the Ashern consists of interbedded greenish grey, dolomitic and silty claystone and greyish brown, very dolomitic and argillaceous siltstone. The massive claystone beds are regularly interbedded with dark grey or green, fissile shale. Some of the more dolomitic beds have a massive aspect and include a scattering of crinoidal debris and nondiagnostic, sediment-filled burrows. Other dolomitic beds are crosslaminated. In sections farther to the west (Strome 11-16-44-16W4 and Strome 8-23-43-16W4 on Fig. 5) the Red River Formation is overlain by a regolith-like conglomerate. The greenish grey, dolomitic and silty claystone beds overlying the conglomerate are poorly bedded and have a bioturbated aspect. They include thin interbeds of dark grey, carbonaceous shale, anhydritic claystone, anhydrite nodules (Plate 1a) and dolomitic interbeds containing fragments of crinoids and brachiopods (Plate 1a, b). The claystone does not contain a lot of clay minerals but is rich in dolomite and silica.

On the crest of the Red River subcrop ridge, where the Ashern Formation is too thin to form a mappable unit (Fig. 5), a similar crinoidal facies directly overlies the regolith-like breccia that marks the top of the Red River Formation at Spiers 11-15-34-15W4. At Link 14-35-34-17W4 the basal Devonian conglomerate includes crinoid ossicles and is only 1 cm thick.

Paleontology

A Middle Devonian assemblage of spores was recovered at Provost 11-35-38-10W4 from two shale beds. The shale bed at 1672 m (GSC loc. C-245073) contains an assemblage of spores including cf. *Contagisporites optivus* (Chibrikova) Owens var. *optivus* and ?*Geminospora lemurata* (Balme) emend. Playford (Plates IV-1 and III-4). An assemblage from the shale bed at 1672.7 m includes fragmentary and abraded nonmarine species. They may have been transported by water for a considerable distance. The carbonaceous material in these and other shale partings at Provost 11-35-38-10W4 includes acritarchs, tasmanitids, chitinozoans, leiospheres and *Gloeocapsomorpha prisca*-like alginite (Plate III-11). *G. prisca* Zalessky is a marine cyanobacterium or green alga, commonly present in some kerogen-rich Ordovician and Devonian strata.

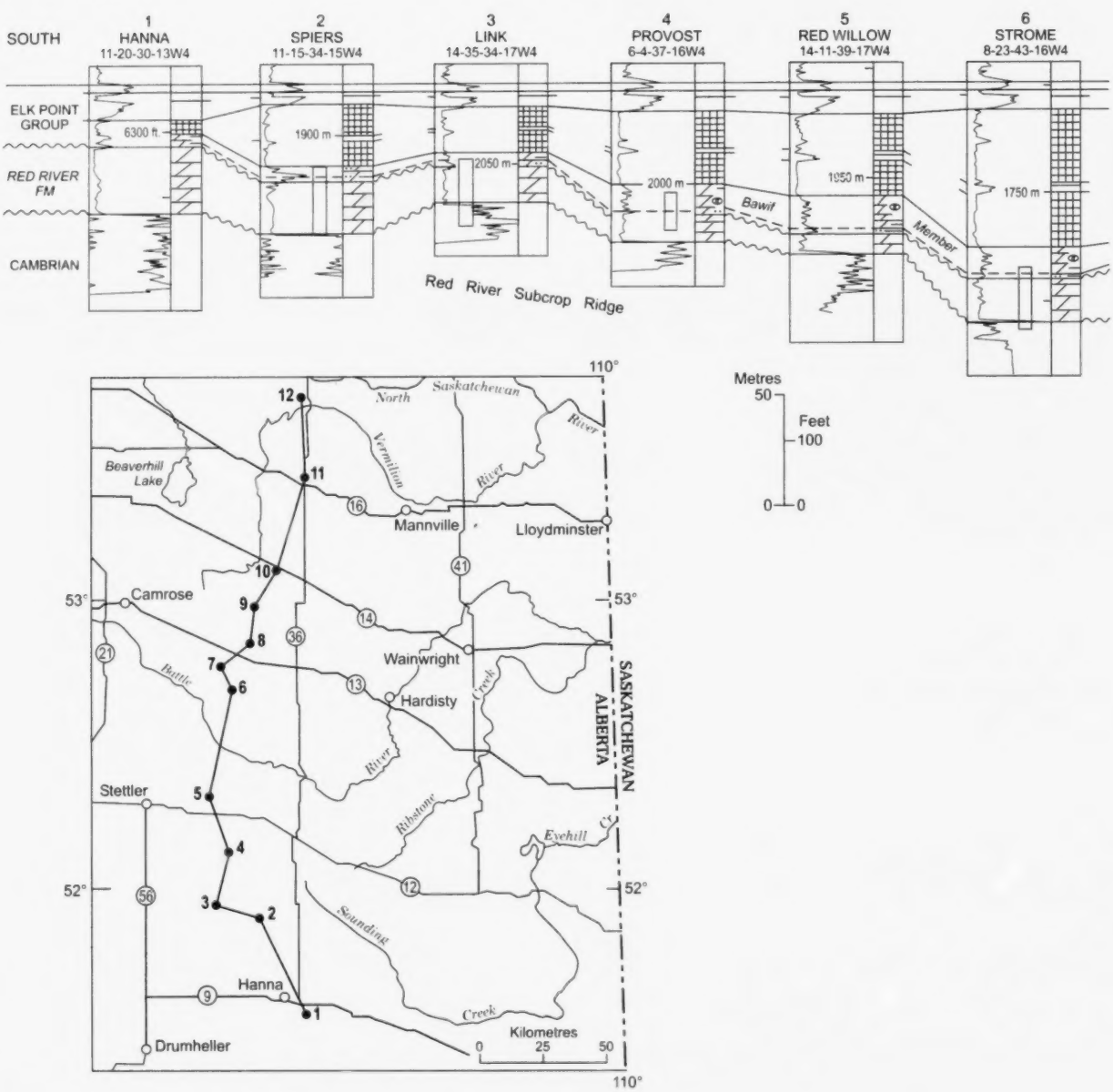


Figure 5. *South-to-north stratigraphic cross-section of the Elk Point strata across Meadow Lake Escarpment, east-central Alberta.*

Geochemistry

At Provost 11-35-38-10W4 (Fig. 8) the silty claystone beds include carbonaceous shale layers with up to 5% total organic carbon (TOC) and hydrogen indices (HI) between 70 and 270 HC/g TOC (Fowler and Stasiuk, 1998a). Thermal maturity profiles for the Provost 11-35 samples, based on vitrinite %Ro and alginite fluorescence properties, indicate that the organic matter is immature to marginally mature.

At Link 14-35-34-17W4 (Fig. 5, sec. 3) a carbonaceous shale sample (2050.86 m) contains 8.4% TOC with a HI of 294. A greenish grey, silty shale sample at 1761 m in the Strome 11-16-44-16W4 section contains 1.2% TOC with a HI of 204. A carbonaceous, silty shale (1472.2 m) at Killam N 15-34-43-10W4 (Fig. 9) contains 5.2% TOC with a HI of 116.

The relatively low HI values in the above samples indicate the presence of Type III kerogen, which is

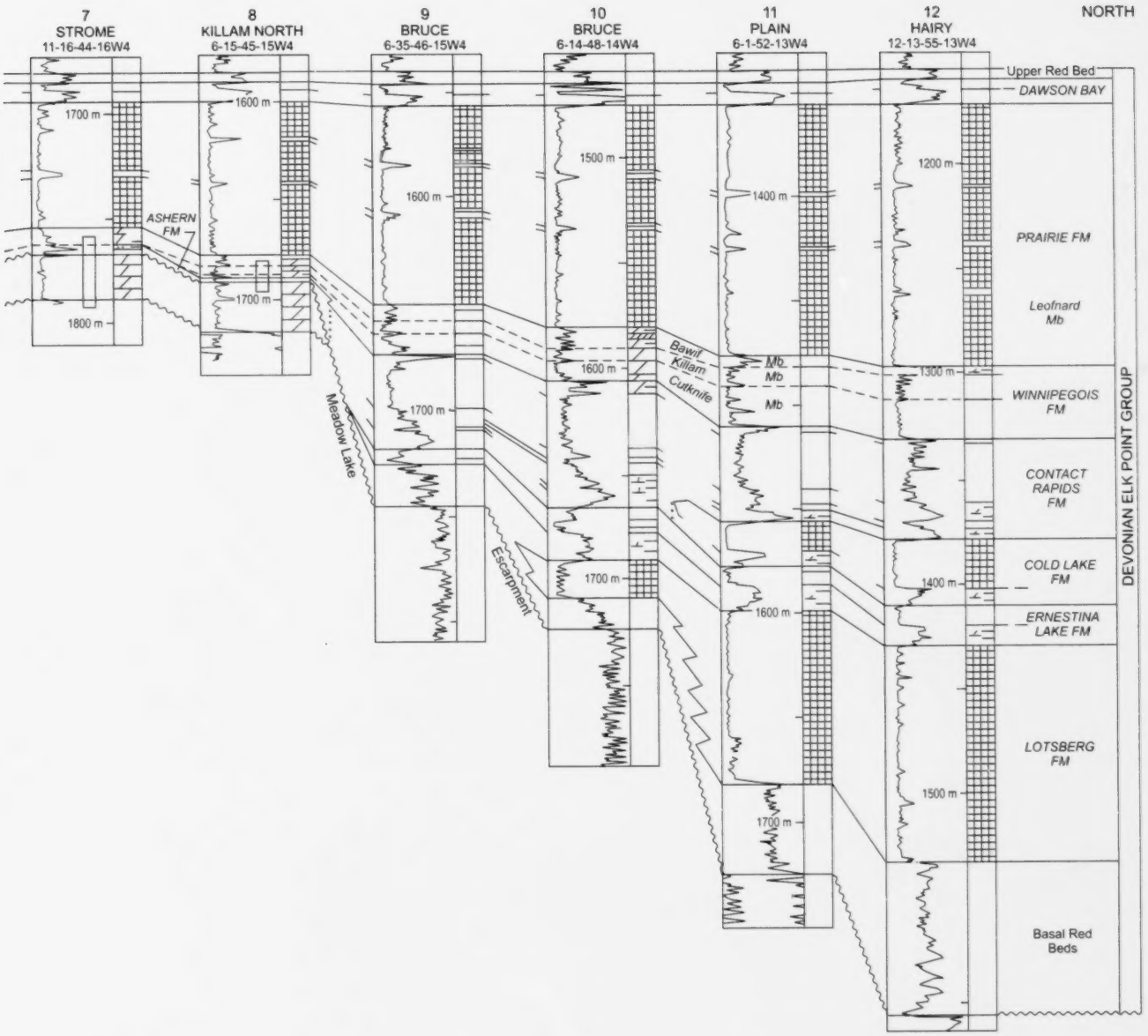


Figure 5 continued.

associated at Provost 11-35-38-10W4 (samples 1672 and 1672.7 m) with remains of land plants or includes (samples 1666.6–1671.2 m) remains of filamentous alginite, *Gloeocapsomorpha prisca*-like alginite, *Leiosphaeridia* and *Tasmanites* alginite (see also Stasiuk, 1999).

Sedimentology

The presence of some nodular anhydrite in the reddish brown, lower part of the Ashern Formation in the outcrop area of southeastern Manitoba (Norris et al., 1982) and the occurrence of salt in the subsurface of west-central North Dakota (Lobdell, 1984), indicate that here the Ashern was deposited in an evaporitic environment. The argillaceous, microcrystalline dolostone in the Tableland region of southeastern Saskatchewan has a bioturbated aspect but does not include diagnostic trace or body fossils (Martindale and MacDonald, 1989).

A conglomeratic mudstone "breccia" is present at the top of the Ashern (Martindale and MacDonald, 1989, plate 1a). A similar conglomeratic mudstone deposit is present in two cored sections in west-central Saskatchewan (Hamil Prov

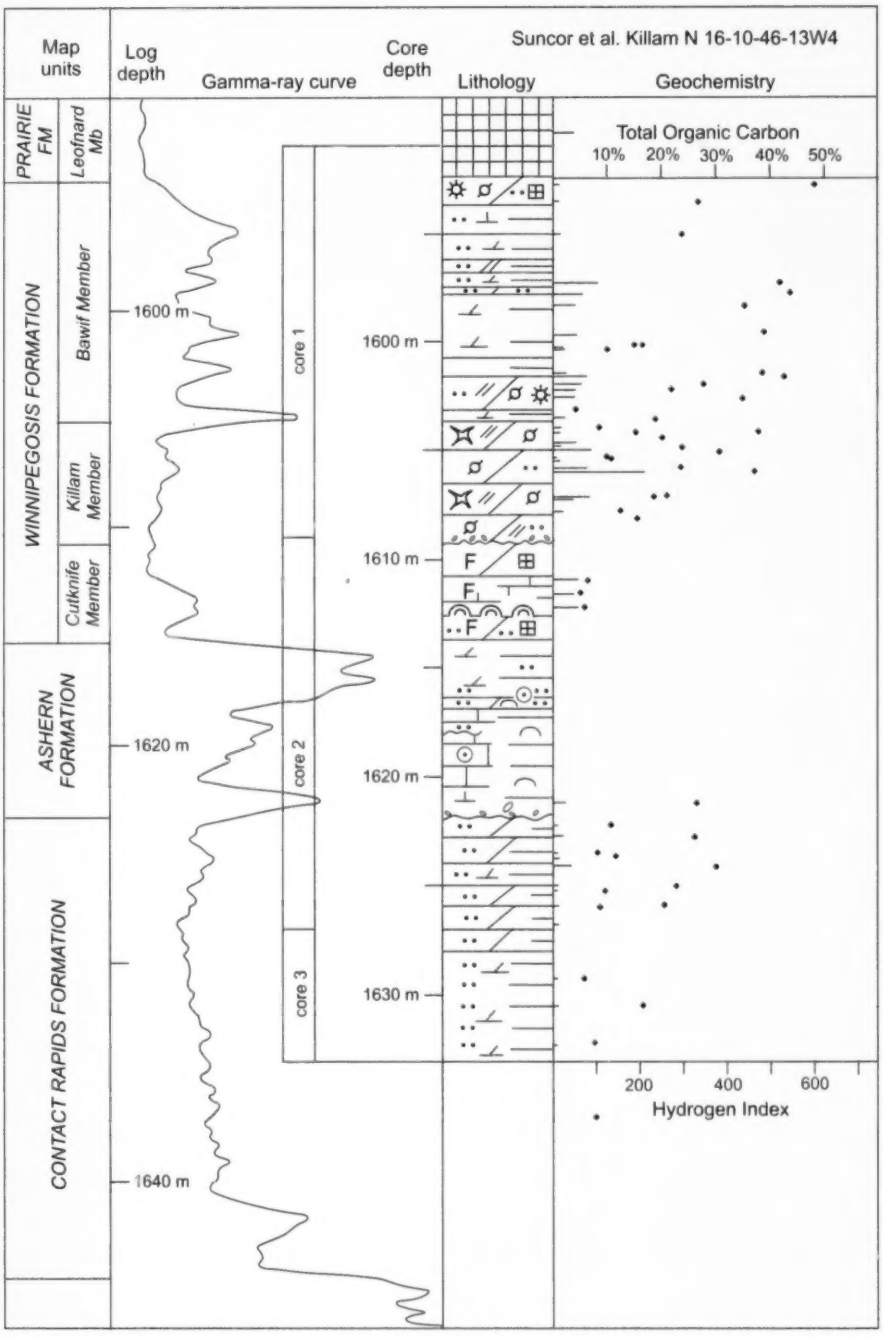


Figure 6. *Geophysical, lithological, and geochemical diagram of Middle Devonian strata at Suncor et al. Killam North 16-10-46-13W4. Stratigraphic units are indicated on the left margin; geophysical borehole information is in the left centre and includes the adjusted cored intervals; lithological information is in the right centre column. The geochemical information in the right margin shows, extending from the vertical (depth) zero line to the right, the total organic carbon (TOC) percentage for each sample. The longer the TOC line, the higher the percentage. The complementary hydrogen index (HI) number for each sample is plotted as a dot. The distance from the zero (depth) line gives the measure of the HI. Thus, at the top, the 1692.5 m sample has a TOC of about 1% and an HI of 590.*

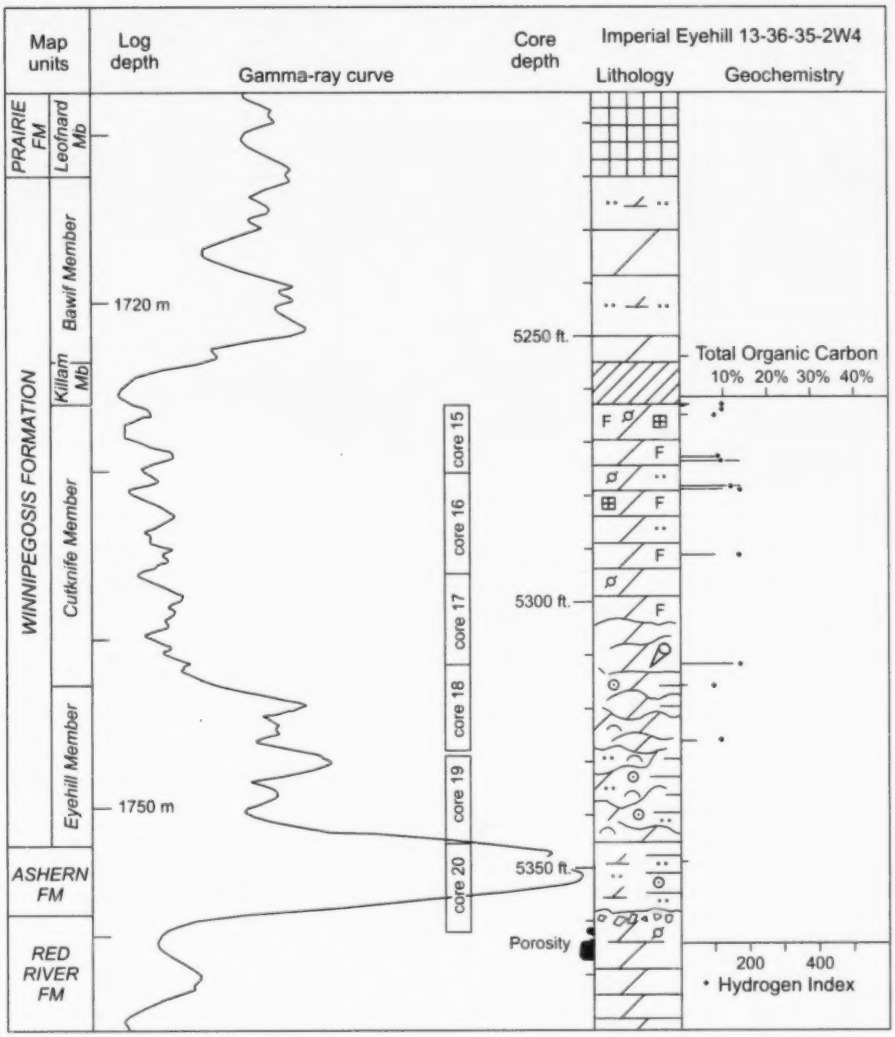


Figure 7. *Geophysical, lithological, and geochemical diagram of lower Paleozoic strata at Imperial Eyehill 13-36-35-2W4.*

1-29-45-16W3 and Allan Crown 16-11-33-1W3). Here the uppermost part of the Ashern Formation consists of greenish grey, argillaceous dolostone and includes nodular, pebble-like mudclasts in a silty and argillaceous matrix.

The west-to-east stratigraphic relationship between the Ashern and Winnipegosis formations depicted in Figure 4, based on geophysical, borehole log correlations, suggests that in east-central Alberta the Ashern (near the limit of its distribution) is in lateral facies contact with the lower part of the Winnipegosis. At the Eyehill section (13-36-35-2W4) the contact between the formations is transitional and the mudstone conglomerate is not present. Thus the mudstone conglomerate could represent a basal transgressive deposit of the Winnipegosis Formation that passes westward into the regolith-like breccia at the pre-Devonian unconformity.

In east-central Alberta the basal trangressive, greenish grey, silty and dolomitic claystone facies of the Ashern Formation lacks diagnostic sedimentary structures. Here the spore-bearing carbonaceous interbeds in the lower part represent lacustrine deposits, while the presence of crinoids in the upper part suggests a marine environment of deposition.

Winnipegosis Formation

The Winnipegosis Formation is a complex group of dolomitized carbonate deposits situated between the siltstone beds of the Ashern Formation (below) and the evaporite deposits of the Prairie Formation (above). In the type area (the outcrop area in southwestern Manitoba) the

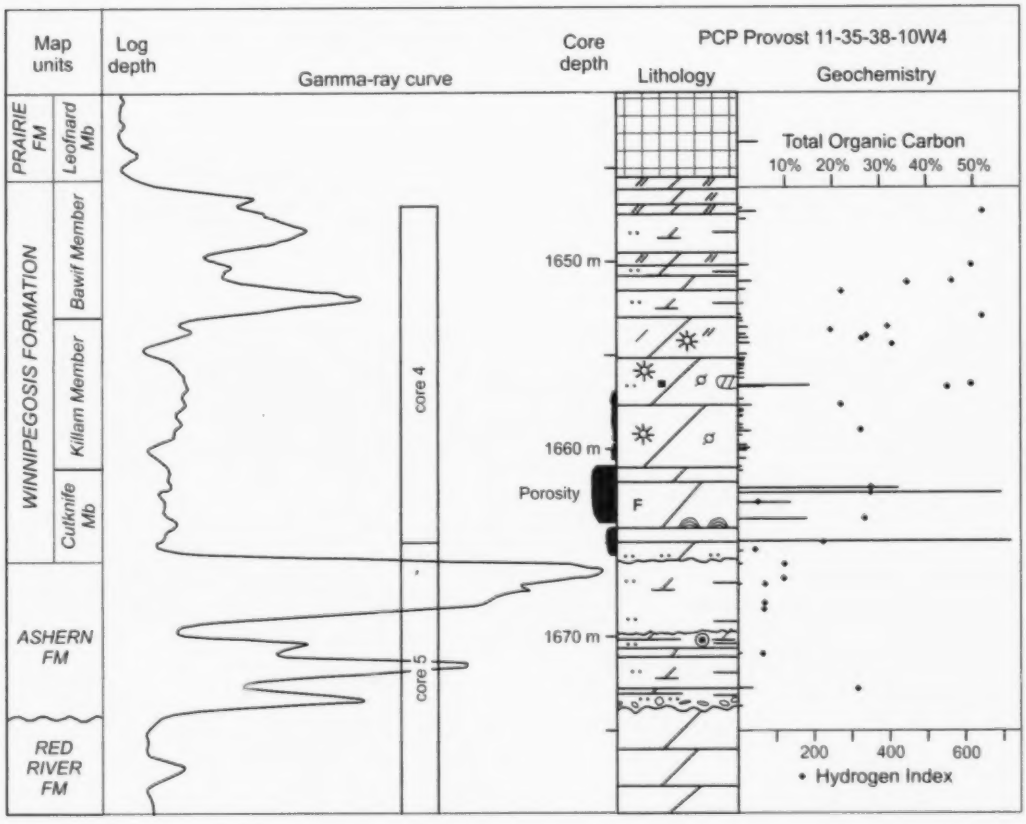


Figure 8. *Geophysical, lithological, and geochemical diagram of Middle Devonian strata at PCP Provost 11-35-38-10W4.*

formation includes platform, reefal mound and intermound facies (Baillie, 1950; Norris et al., 1982). These facies are also present in the subsurface of the central part of the Elk Point Basin. Along the edge of the basin the formation includes an additional, marginal shelf facies, which onlaps the Western Alberta Ridge (Grayston et al., 1964; Perrin, 1982).

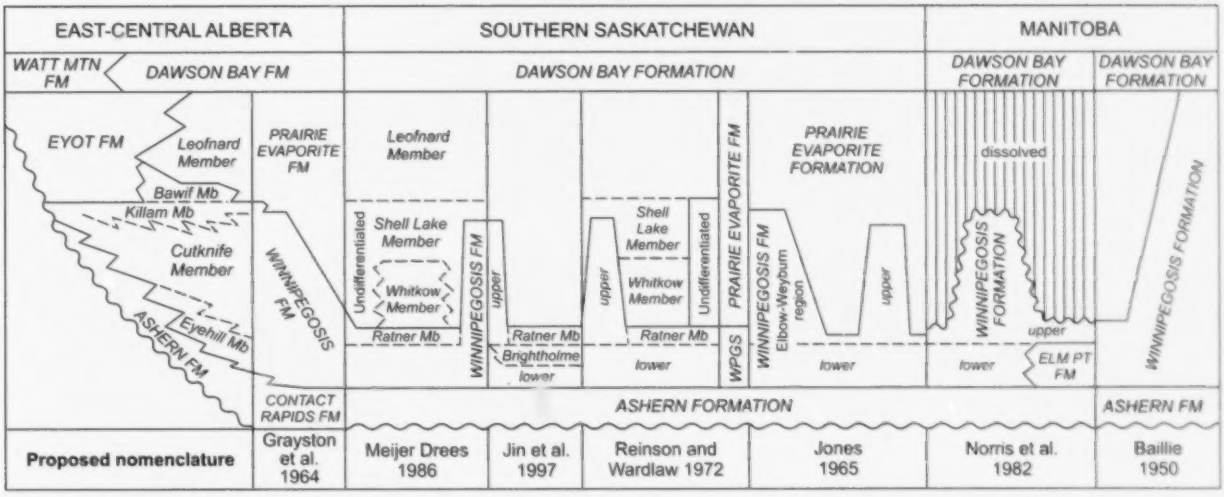
In the outcrop region the carbonate complex is overlain by the Dawson Bay Formation. In the subsurface the carbonate complex is partly overlain by, and in lateral contact with evaporite deposits of the Prairie Formation.

The geology of the Winnipegosis Formation thus includes three settings: 1) the outcrop region along the Canadian Shield; 2) the subsurface region in the central part of the Elk Point Basin in southern Saskatchewan; and 3) the subsurface region along the margin of the Elk Point Basin in southwestern and east-central Alberta (see Fig. 4).

Manitoba outcrop region

The Winnipegosis Formation was first described in the Paleozoic outcrop area of southwestern Manitoba and this region is considered to represent the type area. The Middle Devonian carbonate deposits, exposed along the shores and on the islands in Lake Manitoba and Lake Winnipegosis, were referred by Tyrrell (1892) to the Winnipegosan Formation. Baillie (1950) defined the boundaries of the Winnipegosan with the underlying Ashern Formation and the overlying Dawson Bay Formation and changed the name to Winnipegosis Formation (see Table 1). He considered the Winnipegosis Formation to be equivalent to the combined Elm Point (Kindle, 1914) and Winnipegosan formations. Norris et al. (1982) disagreed and considered that throughout most of the southern part of the outcrop belt, the Winnipegosis Formation includes only the strata between the Elm Point Formation (below) and the Dawson Bay Formation (above); in most of the northern part of the

Table 1
Correlation table of Elk Point Group



outcrop belt the strata equivalent to the Elm Point have been dolomitized, so that here the name Winnipegosis is applied to all the strata between the Ashern and Dawson Bay formations (Table 1).

Baillie (1950) noted the presence of two facies in the outcrop belt. Mound-like exposures of massive dolostone were considered to represent a biohermal facies, and bedded dolostone an inter-reef facies. The study of both surface and subsurface geology in the outcrop belt by Norris et al. (1982) indicates that most of the "inter-reef" dolostone facies described by Baillie (1951) underlies the biohermal facies and is thus laterally equivalent to the Elm Point Formation. Some of the steeply dipping exposures, such as at Rosehill quarry, represent reef-flank, rather than inter-reef deposits.

Not all the facies members within the Winnipegosis occur at one locality. Thus, neither Baillie (1953b) nor Norris et al. (1982) could establish a type section for the Winnipegosis Formation in the outcrop region. However, Norris et al. (1982) established Lower (including the platformal, bedded dolostone facies equivalent to the Elm Point Formation) and Upper members (composed of reefal mounds and bituminous inter-reef deposits) and established subsurface reference sections. They also noted the presence of an uppermost "facies" transitional to the Dawson Bay Formation (see Table 1). These Transition beds consist mostly of limestone-shale breccias and angular to contorted fragments of light brown, recrystallized limestone in a grey clay-shale matrix (Norris et al., 1982, p. 35). They may, in part, represent a leached and collapsed accumulation of the interbeds and impurities of the salt deposits below the Dawson Bay Formation.

The inclusion of the Transition beds with the Winnipegosis Formation and the exclusion of the Elm Point unnecessarily complicate the Elk Point stratigraphy.

The Saskatchewan subsurface region

In the subsurface southwest of the outcrop belt is a region where the salt beds of the Prairie Formation are either not, or only partly, dissolved. Here, Baillie (1953b) defined the Winnipegosis Formation to include all of the carbonate deposits between the Ashern (below) and the evaporite deposits of the Prairie (Evaporite) Formation (above).

In the subsurface of southern Saskatchewan the Winnipegosis overlies the Ashern Formation and includes lithological units similar to those in the outcrop belt. Here Jones (1965) selected the boundary between the Winnipegosis and the Prairie formations at the base of the stratigraphically lowest occurrence of bedded anhydrite. Neither Baillie (1953b) nor Jones (1965) designated a reference section for the Winnipegosis in the subsurface, but Holter (1969) selected a reference section for the Prairie Evaporite Formation at Drake 4-29-32-22W2 (Fig. 10). Here the boundary between the Prairie and Winnipegosis formations was selected between bedded anhydrite (above) and finely crystalline dolostone (below) at 1186.8 m (3894 ft.). The boundary between the Winnipegosis and Ashern formations lies at 1203 m (3947 ft.).

Jones (1965) subdivided the Winnipegosis Formation into lower and upper members (Table 1). He described the lower member as being a widely distributed fossiliferous dolostone unit that includes an argillaceous interval in the

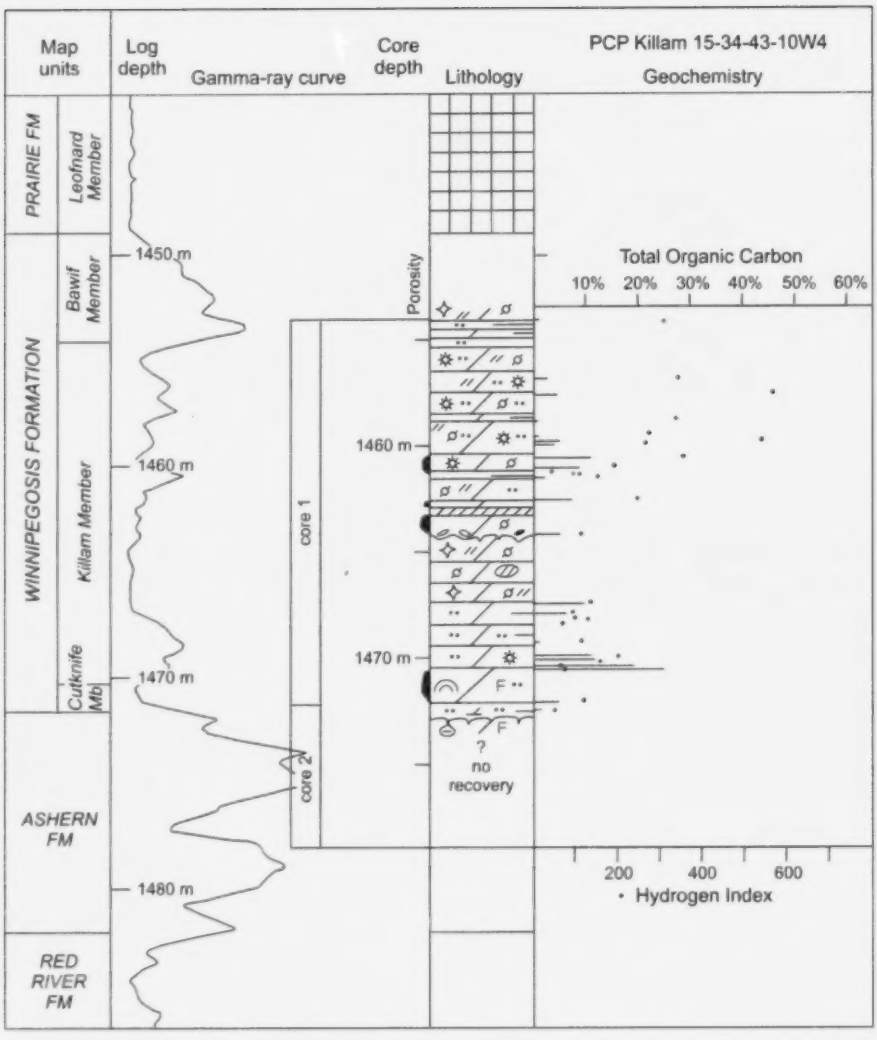


Figure 9. *Geophysical, lithological, and geochemical diagram of Middle Devonian strata at PCP Killam 15-34-43-10W4.*

upper part. This argillaceous interval is a useful marker bed on geophysical borehole logs. The upper member is represented by two facies: a laminated mudstone facies, and a fossiliferous, carbonate mound facies.

Wardlaw and Reinson (1971) described the geology of the Winnipegosis Formation in the subsurface around Saskatoon, and subsequently proposed a threefold subdivision of the Winnipegosis Formation in central Saskatchewan (Reinson and Wardlaw, 1972). They changed the upper boundary of the lower member, formally introduced the Ratner Member for the laminated, anhydritic and carbonate mudstone facies, and retained the upper member to designate the fossiliferous carbonate mound facies.

Kendall (1975) re-examined the subsurface sections in central Sakatchewan and suggested that the argillaceous marker bed in the upper part of the lower Winnipegosis member is coeval with the carbonate mound facies of the upper Winnipegosis member. It is a prominent map unit below the Ratner Member but is thin or absent in the carbonate mount sections.

Recently Jin et al. (1997) restudied the argillaceous marker bed and proposed a local change of the upper boundary of the lower member by introducing the Brightholme Member in south-central Saskatchewan (see Table 1).

Regional correlations on Figure 10 show that the lower and upper members and the Ratner Member of Reinson and Wardlaw (1972) extend westward into west-central Saskatchewan. Here another facies unit (the Elbow-Weyburn Facies of Jones, 1965) is present in the upper part of the Winnipegosis Formation, which overlies the lower member. It forms a marginal carbonate wedge that onlaps the West Alberta Ridge (Grayston et al., 1964; Perrin, 1982) and represents a shelf rather than a mound facies (Fig. 4).

The Alberta subsurface region

Crickmay (1954) traced the equivalents of the Elm Point and Winnipegosan formations on a cross-section into the subsurface of Saskatchewan and Alberta and placed them in the Elk Point Group. Grayston et al. (1964) established the Winnipegosis Formation at Elk Point 2-21-57-5W4, the type section of the Elk Point Group. Here, the upper boundary of the Winnipegosis was placed at the base of the Prairie (Evaporite) salt deposits and the lower boundary selected at the top of the dolomitic shale of the Contact Rapids Formation (Fig. 3). These boundaries define the Winnipegosis Formation in the data file of the Alberta Energy Conservation Board (see Table 1).

Proposal

The above review suggests that the Winnipegosis Formation represents a complex group of map units that may or may not include the limestone beds of the Elm Point Formation and the dissolution breccia of the Transition beds. Such a formation can be best defined as a succession of formally described members.

In order to describe the onlap pattern of the upper Winnipegosis Elbow-Weyburn carbonate shelf facies across the Red River subcrop ridge, it is necessary to formally establish map units and segregate the equivalents of the Winnipegosis Formation from those of the Prairie Formation. In order to avoid the problem of having to accommodate formal members (such as the Ratner and Brightholme members) into a subdivision of informal units, one is obliged to abandon the terms Lower and Upper and replace them with formally named members (see Table 1).

In this report we concern ourselves only with the stratigraphy of the Winnipegosis Formation in the marginal carbonate shelf setting (the Elbow- Weyburn facies) and it is proposed here that the formation be formally subdivided into four members. Not all members can be represented in one type section. Thus it is further proposed that the section at Carruthers 10-11-45-23W3 (Fig. 11) represents the distal part of the Winnipegosis shelf in Saskatchewan and the section at Killam North 16-10-46-13W4 (Fig. 6) the proximal part of the shelf in Alberta.

At Carruthers 10-11-45-23W3 the new members include (in ascending order) the Eyehill and Cutknife members. In the reference section at Killam North 16-10-46-13W4, the new members are (in ascending order) the Cutknife, Killam, and Bawif members (see Table 1).

The stratigraphic relationships on Figure 4 suggest that the Bawif Member overlies a local unconformity and grades laterally eastward into the upper part of the Shell Lake Member of the Prairie Formation. Thus one may argue that the Bawif Member belongs with the Prairie Formation or that it might be a separate formation.

Eyehill Member

It is proposed to apply the name Eyehill Member to the subsurface map unit composed of shaly, nodular-bedded carbonate in the lower part of the Winnipegosis Formation. At Carruthers 10-11-45-23W3 (Fig. 11) in the interval from 1198.4 to 1203.9 m (3932–3950 ft.) the member is about 6 m thick and overlies the Ashern Formation with a sharp contact. The contact with the overlying Cutknife Member is transitional and marked by a decrease in the amount and thickness of the shaly interbeds. The shaly interbeds of the Eyehill Member are visible on the gamma-ray curve as radioactive intervals and this makes the member a distinctive unit on borehole logs.

The type section of the Eyehill Member is located in the Imperial Eyehill No. 1 borehole section (Fig. 7), located south of Provost, at 13-36-35-2W4, in east-central Alberta. Here it is 8.8 m thick and present in the core between 1620.3 and 1629.1 m (5316–5345 ft.). The lower boundary with the Ashern Formation represents a fairly sharp change in lithology but does not include the layer of mudstone pebbles. The boundary with the overlying Cutknife Member is transitional over a 12 cm thick interval and marked by the presence (below) and absence (above) of greenish grey, nodular shale partings in the dolostone.

Stratigraphy

The member can be traced eastward on Figure 12 from Eyehill 13-36-35-2W4 to Luseland 16-36-36-26W3. Streeton (1971, fig. 11) mapped the equivalent in the Luseland area as part of the lower Winnipegosis member. Here it is between 9.4 and 10 m thick. Farther eastward into Saskatchewan, equivalent strata are present at Red Pheasant 13-19-40-15W3 and Drake 4-29-32-22W2 (Fig. 10) below the Ratner Member of Reinson and Wardlaw (1972).

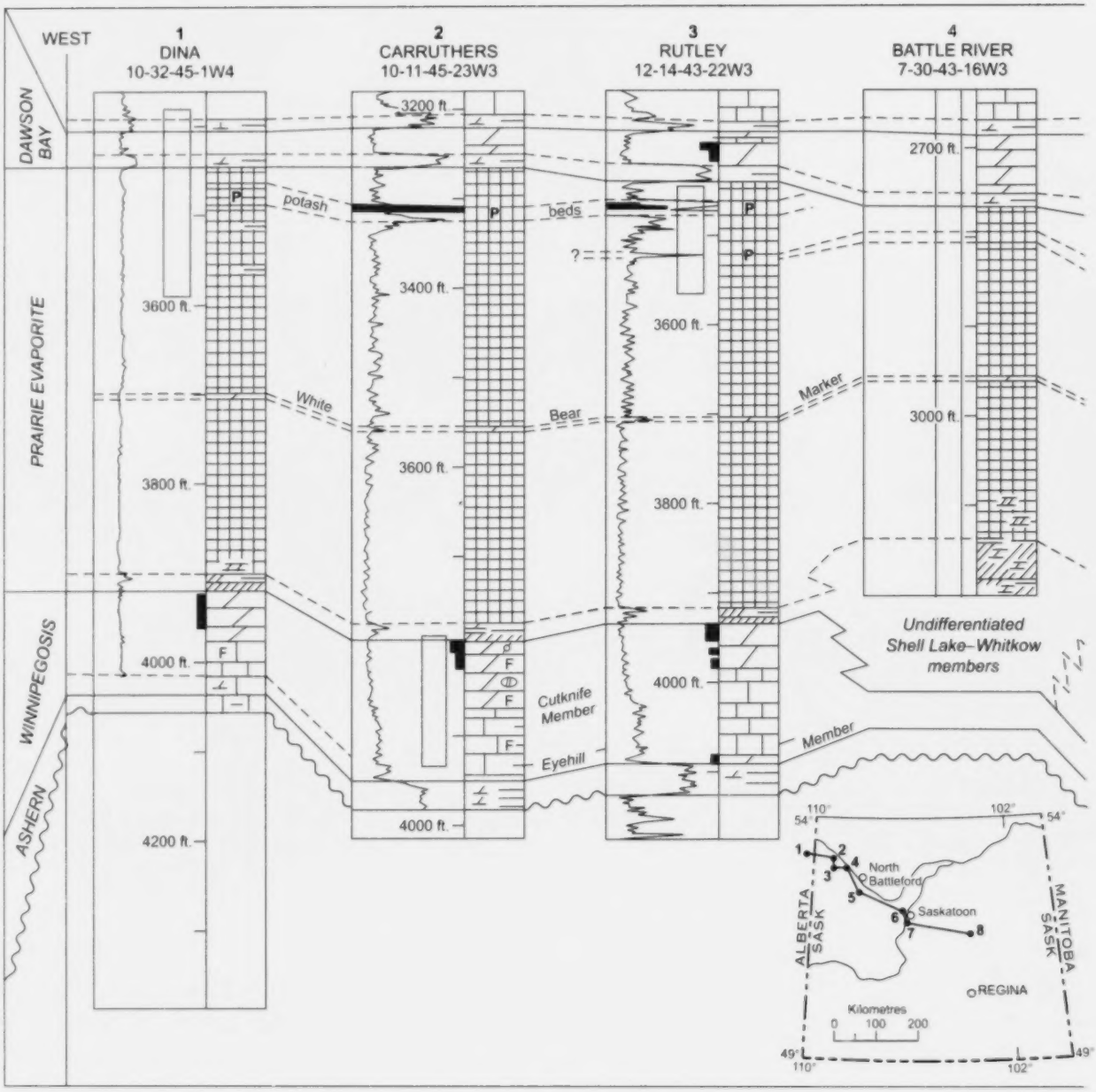


Figure 10. *West-to-east stratigraphic cross-section of Elk Point strata in west-central Saskatchewan (modified from Meijer Drees, 1986).*

The Eyehill Member extends westward, onlaps the eastern flank of the Red River subcrop ridge and merges into the Ashern Formation between sections 7 and 8 (Fig. 12).

At Rutley 12-14-43-22W3 and Carruthers 10-11-45-23W3 (left side of Fig. 10), the Eyehill Member includes a relatively clean carbonate unit at the base. This unit is present in east-central Alberta at Elk Point 2-22-57-5W4 (Fig. 3) and in a number of borehole sections located as far west as Venice 10-12-66-15W4 (Fig. 13).

Regional distribution

In southwestern Saskatchewan the Eyehill Member is widely distributed and underlies the Cutknife Member. In the area north of the Meadow Lake Escarpment in Alberta,

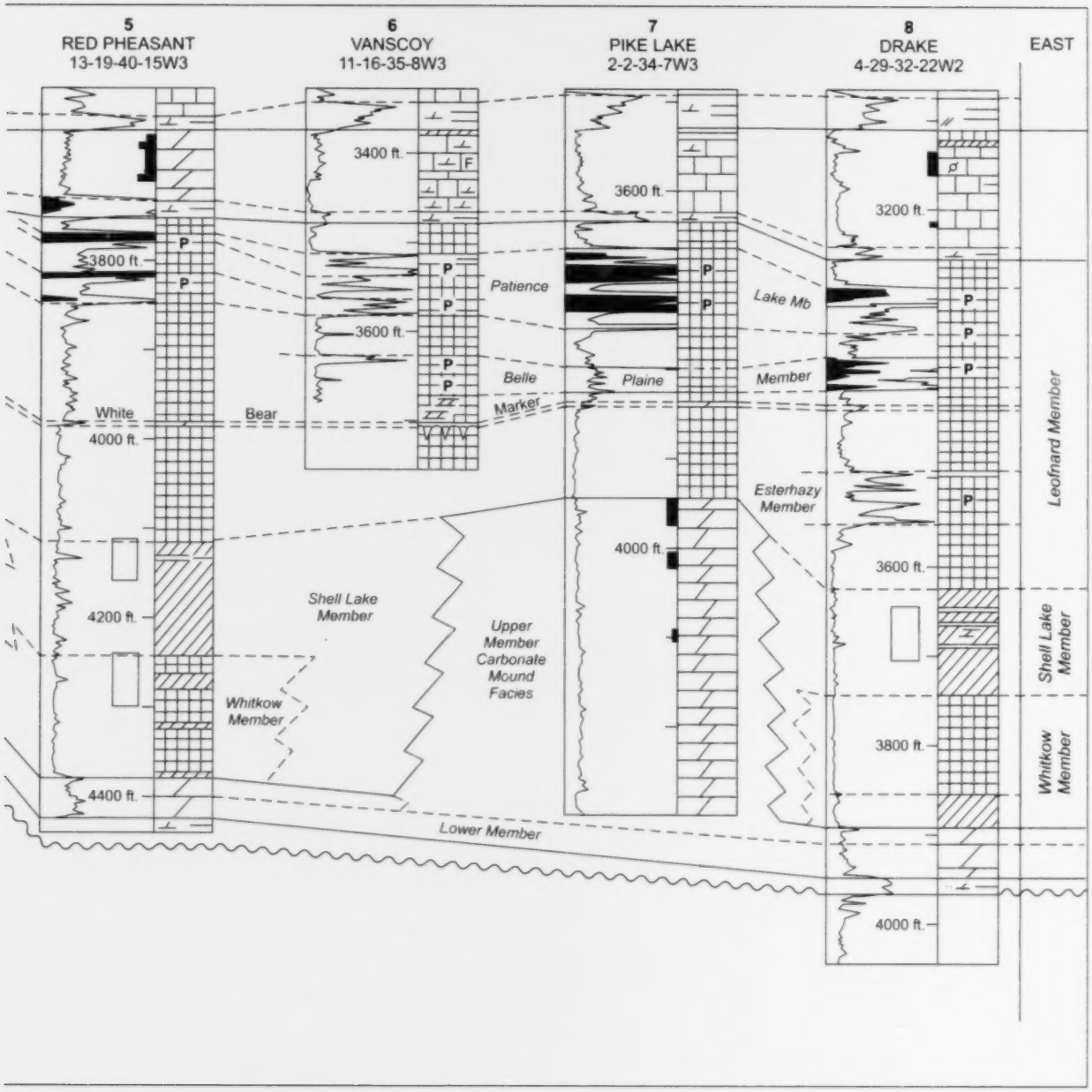


Figure 10 continued.

the member is difficult to recognize on borehole logs because it does not include many shale interbeds. Here the Winnipegosis Formation overlies the Contact Rapids Formation and the absence of shaly interbeds in the basal part of the Winnipegosis sections (northern part of Fig. 5) indicates that the Eyehill Member is not present. Thus the depositional limit of the Eyehill Member (as sketched in Fig. 16) lies somewhere between Venice 10-12-66-15W4 (Fig. 13) and Chrisholm 10-5-68-2W5 (Fig. 14) or Bruce 8-2-46-14W4 (Fig. 15).

Lithology

In the type section the Eyehill Member consists of greyish brown or greenish grey, silty, microcrystalline dolostone,

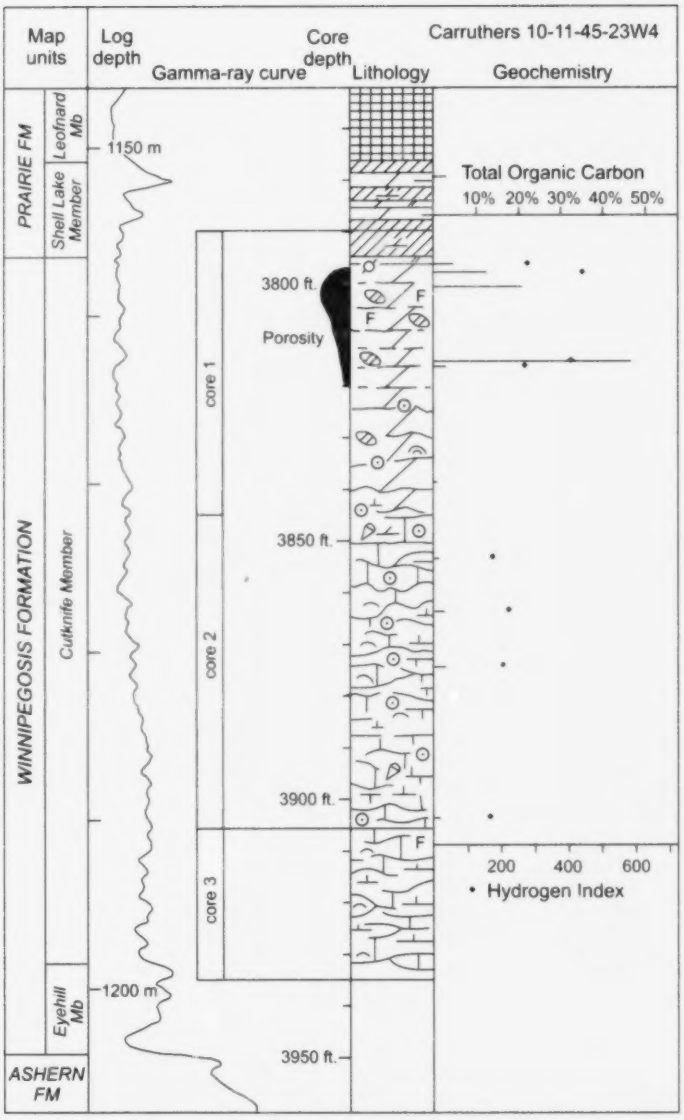


Figure 11. *Geophysical, lithological, and geochemical diagram of Middle Devonian strata at ARCO BA Carruthers 10-11-45-23W3.*

which is nodularly interbedded with dark shale partings. The shale partings occupy between 10 and 20 per cent of the section. The succession has a bioturbated, wackestone aspect and includes a scattering, or locally an abundance, of 2–5 mm crinoid ossicles and brachiopod shell fragments.

Paleontology

The member includes an abundance of crinoid ossicles and smaller amounts of brachiopod shell fragments and corals. Jones (1965) provides a list of fossils that were found in the lower member of the Winnipegosis Formation that includes the brachiopod *Desquamatia* (*Atrypa*) *arctica* Warren. According to Norris et al. (1982) this species is abundantly present in the Elm Point Formation and is locally associated with early Middle Devonian conodonts.

Geochemistry

Two shale samples at Eyehill 13-36-35-2W4 (depths 5326 and 5316 ft.) were analyzed and contain 1.9 and 0.9% TOC with hydrogen indices (HI) of 124 and 101, respectively.

The relatively low HI values indicate the presence of Type III kerogen.

Sedimentology

The peloidal and bioclastic wacke- and packstone in the Eyehill Member have a nodular and bioturbated aspect. Sedimentary structures related to currents and wave-induced turbulence are not present. The presence of corals and crinoids, and the local occurrence of sediment-filled brachiopods that are nearly in growth position, suggest that the carbonate was deposited in a marine, moderately shallow-water environment below fair weather wave base.

Cutknife Member

Massive, fossiliferous, locally porous dolostone that forms the bulk of the Winnipegosis Formation in west-central Saskatchewan and east-central Alberta is assigned to the Cutknife Member. The member is named after a village west of North Battleford and represents the distal part of the marginal-marine carbonate shelf facies in the upper part of the Winnipegosis Formation.

In the type section of the Elk Point Group at Elk Point 2-21-57-5W4 (Fig. 3) the Cutknife Member overlies the Eyehill Member and is overlain by the Killam Member. In the proposed type section of the Cutknife Member at Carruthers 10-11-45-23W3 (Fig. 11), located south of Maidstone in west-central Saskatchewan, the member overlies the Eyehill Member and is overlain by anhydritic beds of the Shell Lake Member (Prairie Formation).

The boundary between the Eyehill and Cutknife members at Carruthers 10-11 more or less coincides with the boundary between the lower and upper members of the Winnipegosis Formation of Jones (1965) and Streeton (1971). It is selected at 1198.1 m (3931 ft.). At Carruthers 10-11 the Killam Member is not present because of a facies change to anhydrite of the Shell Lake Member. Here the Cutknife is overlain by the Bawif Member and the boundary between the Cutknife and Bawif members lies at the base of the stratigraphically lowest occurrence of bedded anhydrite at 1156.5 m (3794.5 ft.). This boundary coincides with the contact between the Winnipegosis and Prairie formations as defined by Jones (1965) and Holter (1969).

In east-central Alberta, at Elk Point 2-21-57-5W4 (Fig. 3), an interbedded unit of anhydritic and peloidal dolostone (the Killam Member) has replaced the unit of bedded anhydrite. Here the top of the Cutknife Member is selected at the base of a radioactive and dolomitic claystone bed (Bawif Member) below the Prairie salt deposits.

Stratigraphy

The correlations in west-central Saskatchewan between the Cutknife Member and the informal and formal map units of Reinson and Wardlaw (1972) are shown schematically in Figure 10. It is shown that the lateral transition between the upper part of the Winnipegosis at Rutley 12-14-43-22W3 and the lower part of the Prairie Formation at Red Pheasant 13-19-40-15W3, involves an anhydritic facies (the "undifferentiated Shell Lake-Whitkow" unit of Reinson and Wardlaw, 1972) which occupies a position between the fossiliferous carbonate of the Cutknife Member and the salt deposits of the Whitkow Member.

A comparison is shown on Figure 10 between the sections of the upper Winnipegosis member at Pike Lake 2-2-34-7W3 and the Cutknife Member at Carruthers 10-11-45-23W3. It is evident that the gamma-ray signature of the Cutknife Member is different from that of the upper member of the Winnipegosis Formation. The Cutknife is a relatively thin unit that, based on analysis of the gamma-ray curve, includes a lower, argillaceous, and an upper, nonargillaceous part.

The stratigraphic relationships across the Red River subcrop edge, shown on Figures 5 and 12, indicate that the Winnipegosis Formation is represented by the Cutknife, Killam, and Bawif members. On Figure 5 the Cutknife directly overlies the Contact Rapids Formation and extends southward across the Meadow Lake Escarpment. At Killam North 6-15-45-15W4 (Fig. 5) the Cutknife Member overlies the equivalent of the Ashern Formation and is represented by a basal bioclastic facies (1686.67–1689.65 m). The basal bioclastic facies is absent at Strome 11-16-44-16W4 because of nondeposition or erosion prior to the deposition of the Bawif Member.

The east to west onlap across the Red River subcrop ridge visible on Figure 12 is not known in detail because of a lack of cored sections. However, the Cutknife Member extends westward beyond the depositional limit of the Eyehill Member and decreases in thickness from 25 m at Luseland 16-36-36-25W3 to 0 m at Hamilton Lake 8-15-35-10W4. The correlations between these sections suggest that the lower part of the Cutknife Member is in lateral contact with the Ashern, while the upper part is truncated by the Bawif Member.

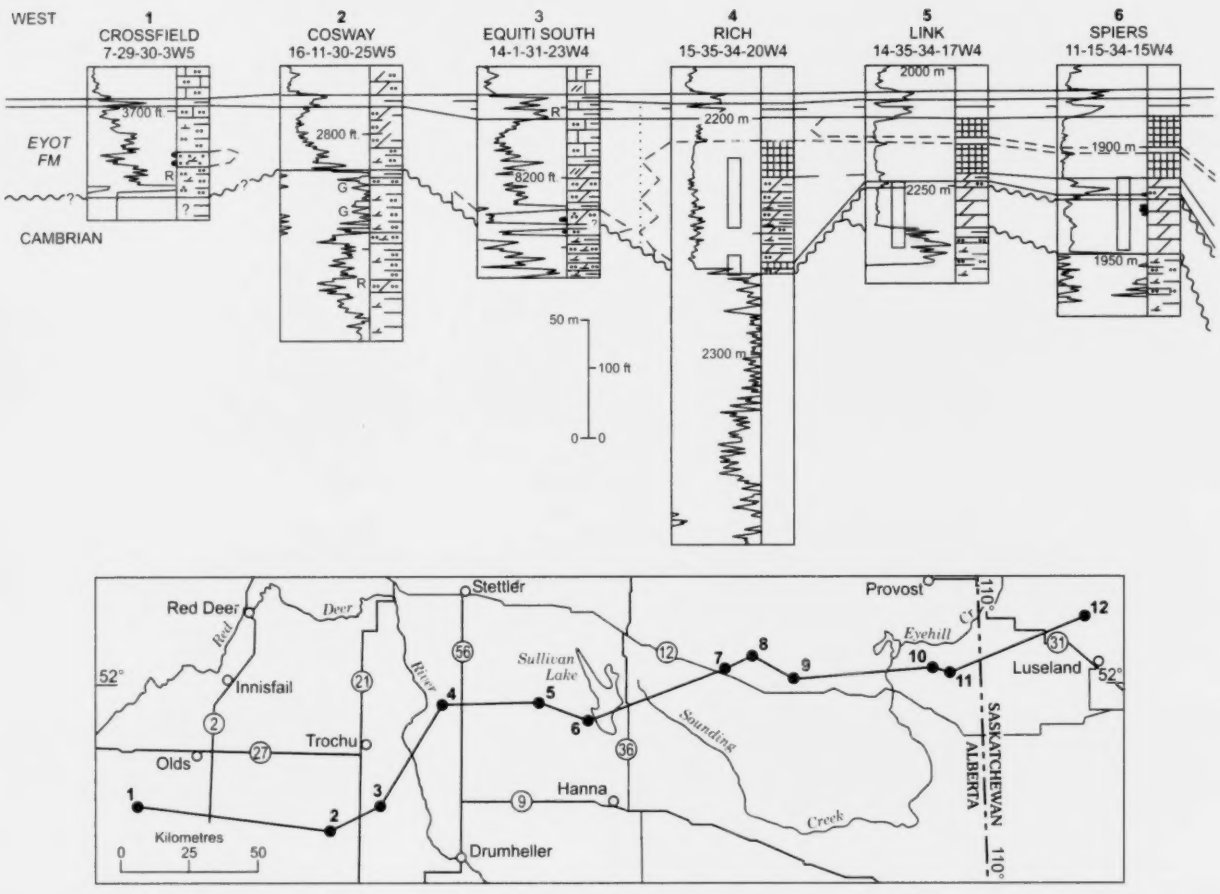


Figure 12. *West-to-east stratigraphic cross-section of the Middle Devonian strata across the Red River subcrop ridge in east-central Alberta.*

Regional distribution

The Cutknife Member is widely distributed in southeastern Alberta and southwestern Saskatchewan. It extends into the northeastern part of Montana and the northwestern part of North Dakota, where it was mapped as a marginal-marine shelf facies of the Winnipegosis Formation or as part of the upper member of the Winnipegosis Formation (Grayston et al. 1964; Fuzesy, 1975; Perrin, 1982).

In east-central Alberta, north of the Meadow Lake Escarpment, the Cutknife Member overlies the Eyehill Member and is overlain by the Killam Member. It extends northward into the upper part of the Keg River Formation. Here it decreases in thickness toward the highland on the Peace River Arch because of a facies change to clastic sediments (see Meijer Drees, 1994, Fig. 16).

In central Alberta the member decreases in thickness toward the southwest. Along the margin of the western extension of the Meadow Lake Escarpment (Fig. 16) a facies change to silty and sandy dolostone complicates correlations. Without detailed lithological information from cores it is not possible to draw the depositional limit.

In east-central Alberta, south of the Meadow Lake Escarpment, the Cutknife Member onlaps local high areas on the pre-Devonian unconformity near the subcrop edge of the Ordovician Red River Formation (Fig. 16).

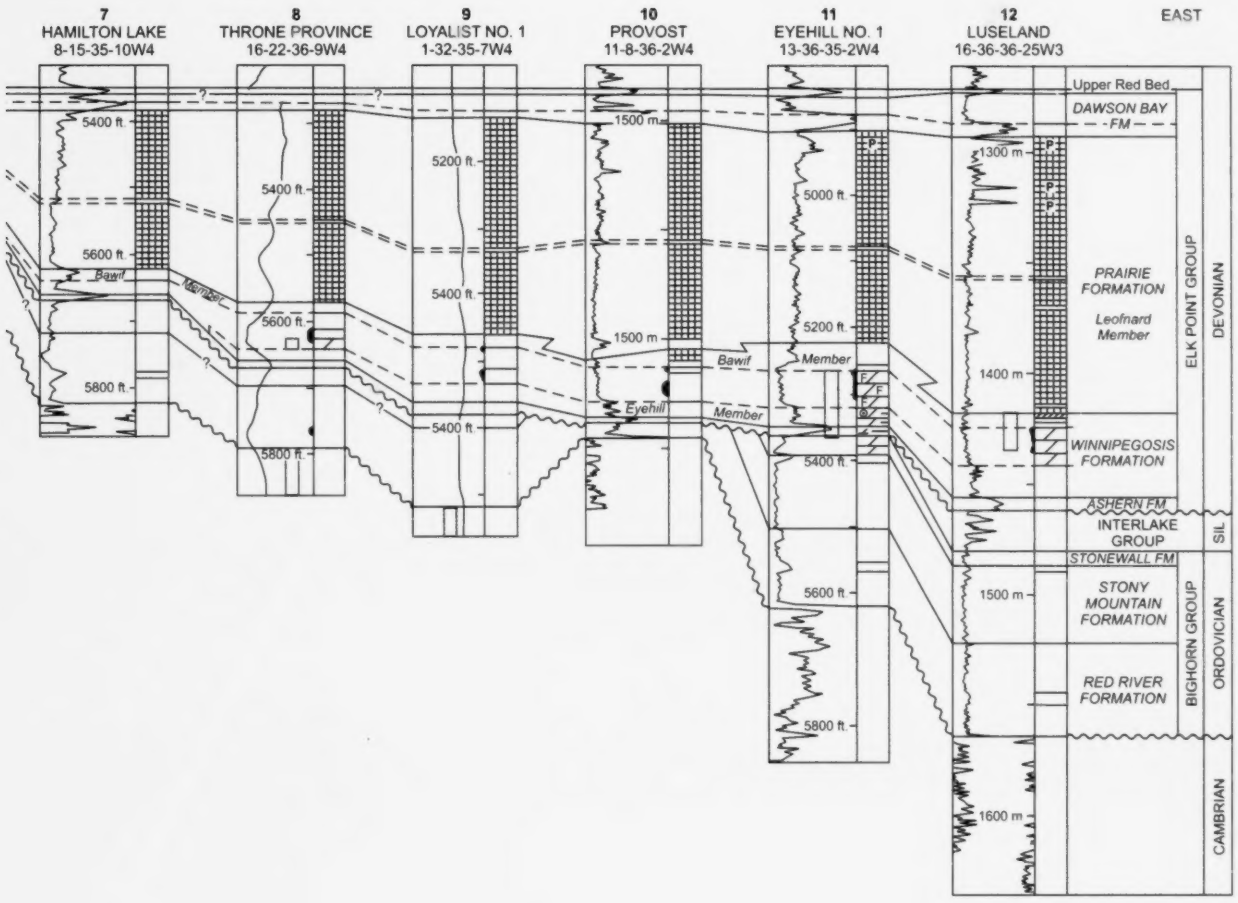


Figure 12 continued.

It is assumed that the eastern depositional limit of the Cutknife Member in west-central Saskatchewan represents an ancient (clinoform) shelf edge (Meijer Drees, 1985) that parallels the western limit of Whitkow salt and trends northwestward into northeastern Alberta and southwestward to North Dakota.

Lithology

The gamma-ray curve at Carruthers 10-11-45-23W3 (Fig. 11) suggests that the Cutknife Member includes lower, argillaceous and upper, nonargillaceous parts. However, the change in lithology at approximately 1165.5 m (3824 ft.) from limestone (below) to dolostone (above) is more prominent than the subtle gamma-ray change from argillaceous to nonargillaceous carbonate at 1182 m (3878 ft.).

At Carruthers, the interval from 1182 to 1198.4 m (3878–3932 ft.) comprises a greyish brown, nodular limestone interbedded with (between 20 and 40%) dark greyish brown marlstone. The limestone is a peloidal wacke- or packstone including fragments of thamnoporid corals, brachiopods, crinoids and ostracodes (Plate 1c). Interval 1171.9–1182 m (3845–3878 ft.) is a similar, nodular and in part dolomitic wackestone that is interbedded with up to 20% dark greyish brown marlstone. Interval 1165.5–1171.9 m (3824–3845 ft.) consists of greyish brown dolostone. It includes calcareous patches that contain scattered fragments of brachiopods, bulbous stromatoporoids and crinoids. White veins and irregular inclusions of anhydrite are also present.

The upper, nonargillaceous part of the Cutknife Member at Carruthers (interval 1156.5–1165.5 m or 3794.5–3824 ft.) consists of light to greyish brown, very fine- to fine-crystalline, porous dolostone that has a massive, peloidal

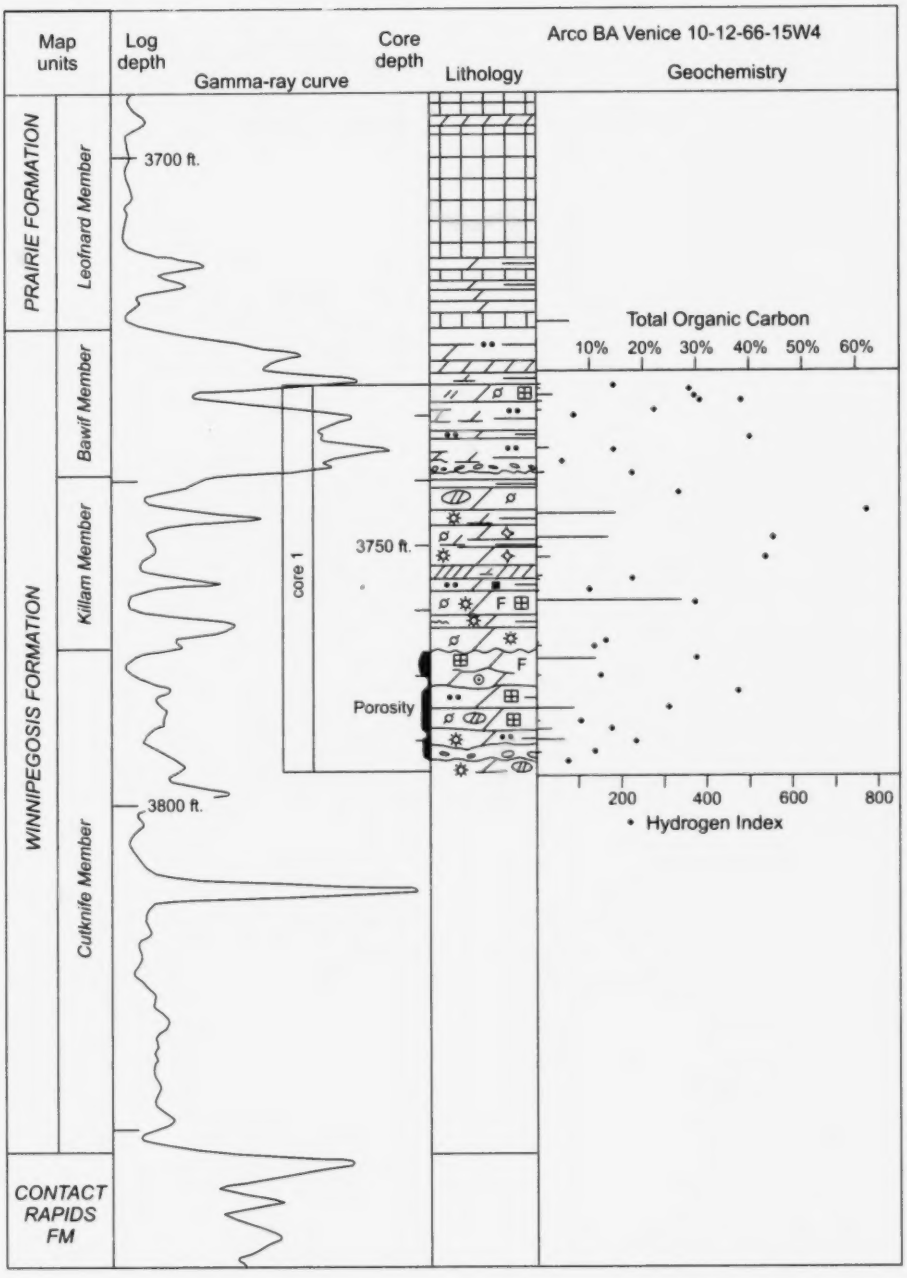


Figure 13. *Geophysical, lithological, and geochemical diagram of Middle Devonian strata at ARCO BA Venice 10-12-66-15W4.*

grainstone aspect (similar to Plate Id) and includes scattered dark grey, undulating and discontinuous shale partings. Also present are veins and nodular inclusions of white anhydrite, some of which may represent leached, digitate stromatoporoids. Just below the upper boundary the dolostone is anhydritic and is interlaminated with carbonaceous shale partings in a wavy manner. Here the dolostone has a finely peloidal aspect. The contact with the overlying Shell Lake Member at 1156.5 m is transitional and marked by an upward increase of anhydrite in the form of cement and nodular interbeds (see Meijer Drees, 1985, fig. 54c).

The upper part of the Cutknife Member was cored in a number of other boreholes in Saskatchewan including those at Poundmaker 12-28-45-22W3, Luseland 16-36-36-25W3

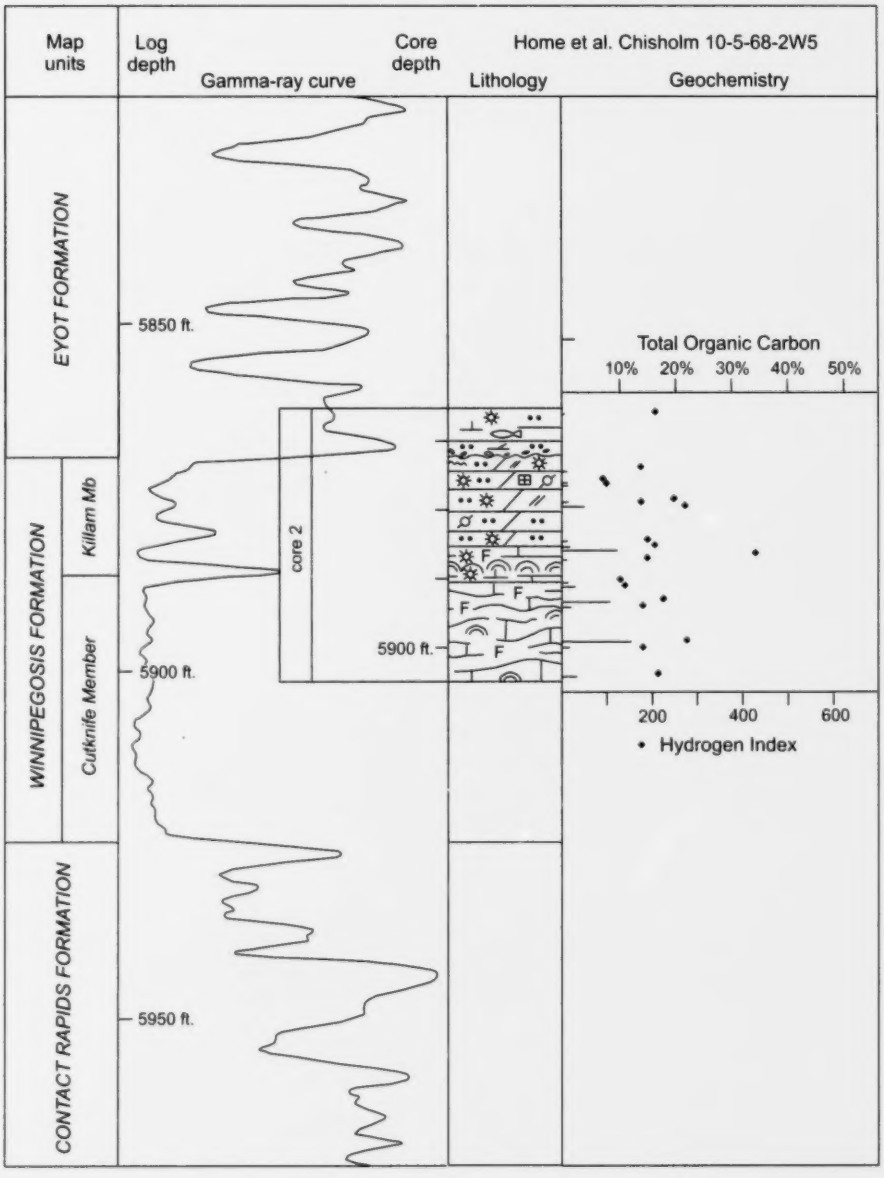


***Figure 14**. Geophysical, lithological, and geochemical diagram of Middle Devonian strata at Home et al. Chisholm 10-5-68-2W5.*

(Fig. 17) and Reward 4-28-38-24W3. In these sections the lithology is similar to that shown in Plate Id and the boundary with the overlying anhydritic Shell Lake Member is either sharp, as at Poundmaker (Meijer Drees, 1985, fig. 54a), or transitional over a distance of 5 cm, as at Carruthers.

At Eyehill 13-36-35-2W4 (Fig. 7), in east-central Alberta, the dolostone is greyish brown, very fine- to fine-crystalline, silty and locally porous. It has a peloidal pack- to grainstone aspect and includes undulating, thin, dark grey, carbonaceous shale partings. Just below the top are fossiliferous interbeds that contain poorly preserved fragments of ostracodes, charophytes, brachiopods, gastropods, corals and amphiporids (Plate Ie).

The upper, nonargillaceous part of the Cutknife Member was also cored at Throne Province 16-22-36-9W4 (Fig. 12, section 8) and at Marwayne 14-29-52-2W4. In both sections the lithology is similar to that described above, indicating that the dolomitized, fossiliferous, peloidal pack- to grainstone facies is widely distributed.

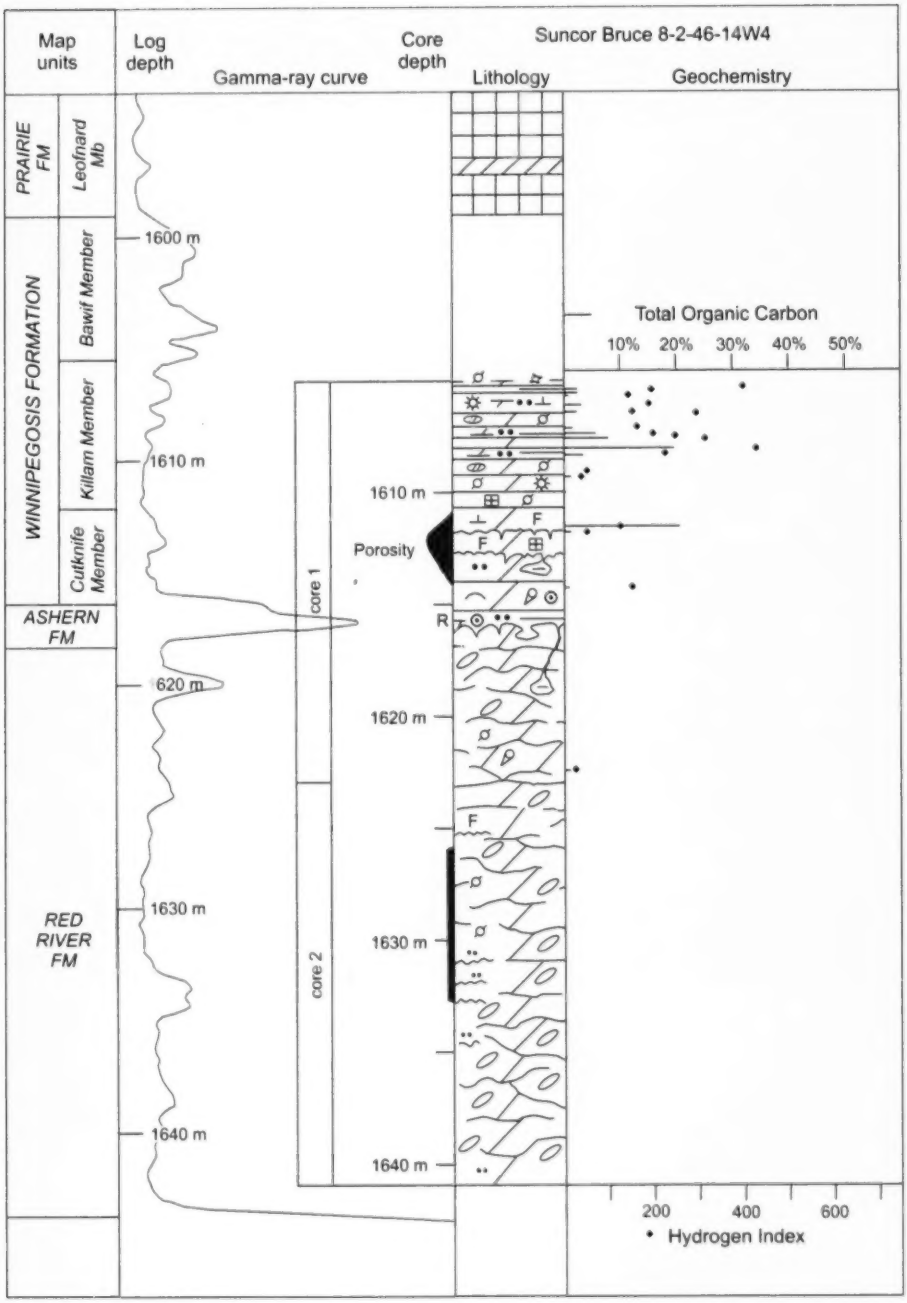


Figure 15. *Geophysical, lithological, and geochemical diagram of Middle Devonian strata at Suncor Bruce 8-12-46-14W4.*

Basal bioclastic facies

In east-central Alberta along the subcrop ridge of the Red River Formation where the Eyehill Member is not present, the basal part of the Cutknife Member includes a basal bioclastic facies of poorly sorted, partly or completely dolomitized, fossiliferous rud- and floatstones, interbedded with dark grey, fossiliferous and very silty marlstone and

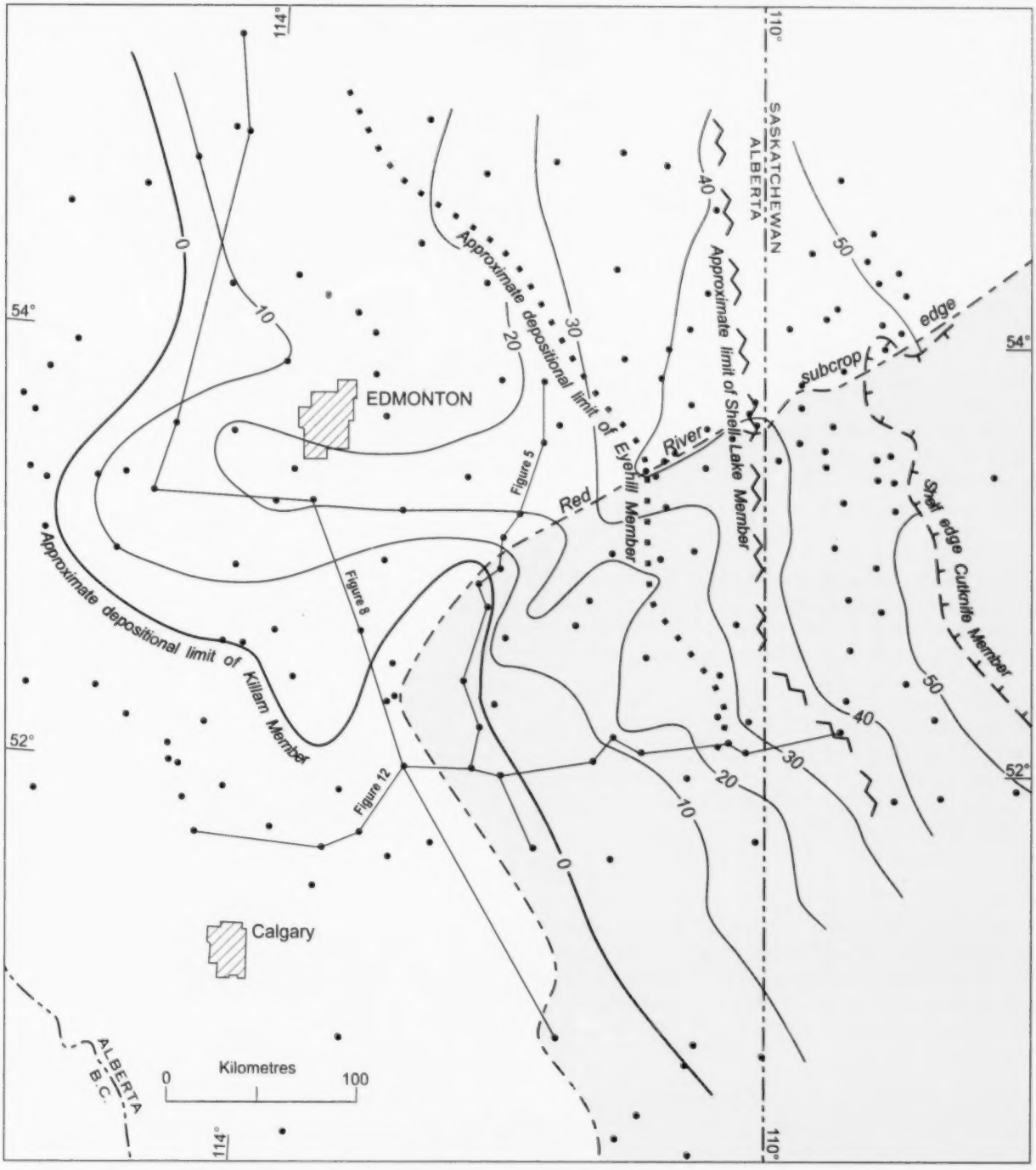


Figure 16. *Isopach map of the combined Eyehill and Cutknife members, east-central Alberta and west-central Saskatchewan. Solid circles indicate selected borehole locations.*

minor carbonaceous shale. The large fossils, including tabular, bulbous and digitate stromatoporoids, are well preserved in the limestone beds (Plate 2f) but poorly preserved and partly leached in the dolomitic beds (Plate 1c). At some locations (Provost 11-35-38-10W4, Fig. 8, and Killam 15-34-43-10W4, Fig. 9) the lower

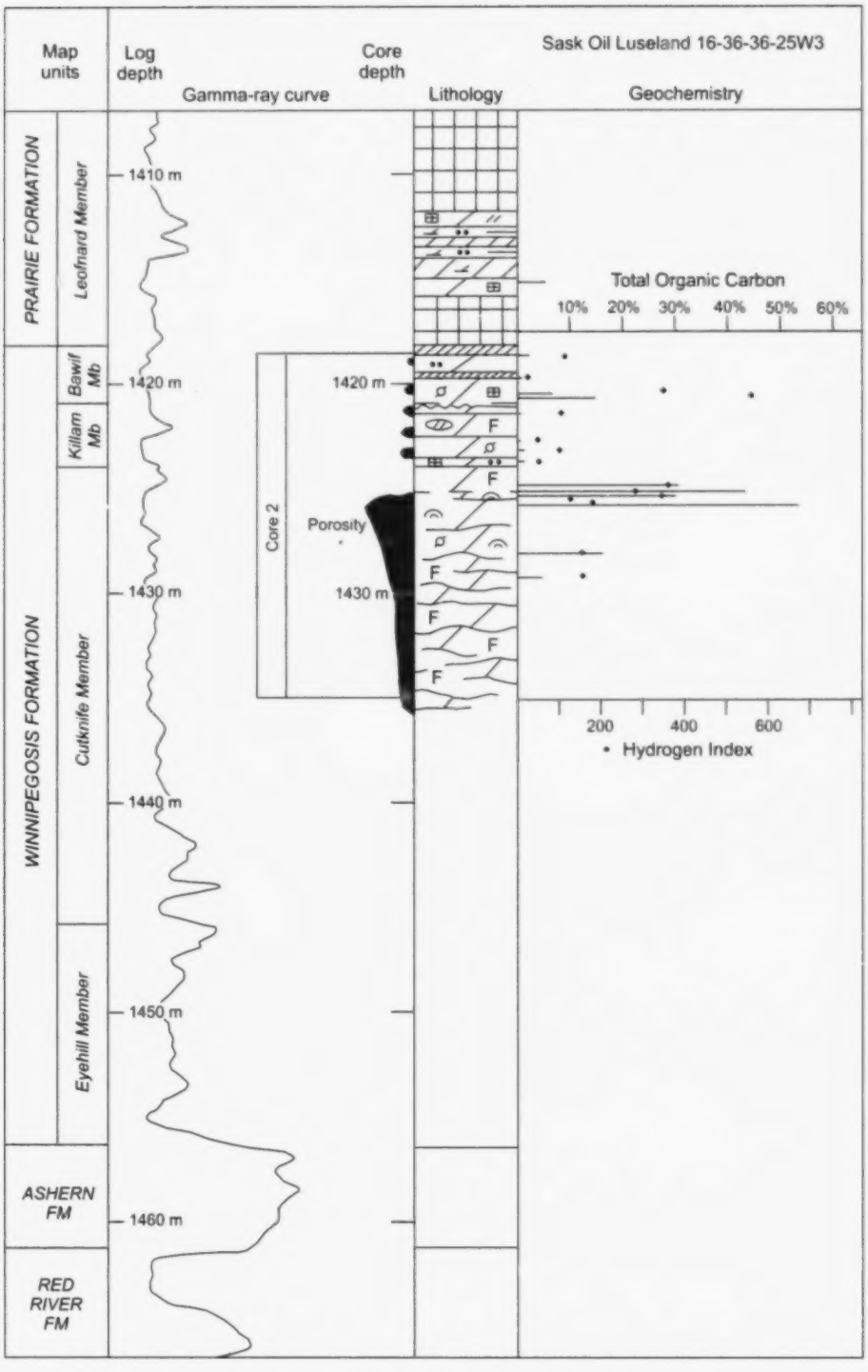


Figure 17. *Geophysical, lithological, and geochemical diagram of Middle Devonian strata at Sask Oil Luseland 16-36-36-25W3.*

boundary with the Ashern Formation is erosional; at others (Killam N 16-10-46-13W4, Eyehill 13-36-35-2W4 and Bruce 8-2-46-14W4) the contact with the Ashern Formation, or the Contact Rapids Formation, is conformable. The bioclastic facies is locally overlain with an erosional contact by the Killam Member (e.g., at Killam N 16-10-46-13W4, Fig. 6, and Bruce 8-2-46-14W4, Fig. 15).

The bioclastic facies of the Cutknife Member is also present in central Alberta, at Chisholm 10-5-68-2W5 (Fig. 14). Here the pack- and rudstone are composed of fragments of crinoids, brachiopods, corals and gastropods. Some of the tabular and bulbous stromatoporoids may be in growth position. Here dark grey, silty marlstone interbeds contain crinoid ossicles and charophyte oogonia.

Paleontology

Mid-Eifelian to mid-Givetian conodonts were recovered in the lower part of the Cutknife Member in a sample between 1189.9 and 1190.2 m (3904–3905 ft.) at Carruthers 10-11-45-23W3 (Fig. 11). The presence of *Dvorakia* sp. and *Icriodus* cf. *I. stephensoni* Sparling indicate an age range from the *australis* Zone to Middle *varcus* Subzone.

A large *Stringocephalus*-like brachiopod is present in the upper part of the Cutknife Member at Marwayne 14-29-52-2W4. This brachiopod is diagnostic for the Givetan Stage. Crickmay (1954, 1960) described several stringocephalid species and Jones (1965) commented on their distribution in the Winnipegosis Formation.

A thin carbonaceous shale layer at 3495 ft. (1065.27 m) in the upper part of the Cutknife at Marwayne 14-29-52-2W4 yielded Middle Devonian spores from land plants, including *Grandispora velata* (Eisenack) Playford, *Emphanisporites* sp. nov. and possibly *Acinosporites*, ?*Auroraspora*, *Geminospora*, and *Rhabdosporites*.

Incident light microscopy on polished sections of selected shale beds from the upper Cutknife in Saskatchewan has identified a mixture of chitinous (scolecodonts), carbonate (ostracodes) and carbonaceous (spores and algae) fossil debris.

A limestone sample of the bioclastic facies at Provost 11-35-38-10W4 yielded long-ranging conodonts (Uyeno pers. comm., 1998). Massive amounts of amorphous kerogen, leiospheres and several degraded and corroded spores are present in a carbonaceous shale sample at 1663.5 m (Nowlan 1998a).

Two shale layers at Kinsella 6-14-46-9W4 contain miospores, scolecodonts, acritarchs, prasinophytes, and remains of coccoidal algae.

Geochemistry

The scattered dark grey, carbonaceous shale partings and beds in the Cutknife Member range in thickness between 0.1 and 0.5 cm. The total organic content (TOC) (measured by Rock-Eval pyrolysis) of many of the shale beds from four sections in Saskatchewan (Carruthers, Poundmaker, Luseland and Reward) ranges between 30 and 50 wt.% with hydrogen indices (HI) between 100 and 400.

In east-central Alberta similar, thin shale partings at Eyehill 13-36-35-2W4, Throne Province 16-22-36-9W4 and Kinsella 6-14-46-9W4 contain between 0.35 and 43.02% TOC and the HI range between 25 and 277. The spore-bearing shale parting at Marwayne 14-29-52-2W4 at 1065.27 m (3495 ft.) is characterized by a TOC of 0.35% and a HI of 277.

The relatively low hydrogen indices of the organic material in the above samples agree with microscopic observations that the organic matter is mostly derived from terrestrial plants (Fowler and Stasiuk 1998a).

The dark grey marlstone beds in the basal bioclastic facies at Chisholm 10-5-68-2W5 contain between 0.71 and 12.6% TOC and the HI range between 130 and 277. One very dark shale parting at 1794.28 m (5886.75 ft.) measured 8.85% TOC and had a HI of 429 (Fig. 14).

Sedimentology

The well-sorted, dolomitized, peloidal grainstone in the upper part of the Cutknife Member lacks diagnostic sedimentary structures. The presence of laminar and digitate stromatoporoids in the pack- and grainstone suggests a marine, shallow-water, possibly semirestricted environment above fair weather wave base.

The basal bioclastic facies that fringes the Red River subcrop ridge is fine- to coarse-grained and includes large, bulbous and tabular stromatoporoids that are thought to have grown in marine, moderately turbulent, shallow water. The dark coaly interbeds at Provost 11-35-38-10W4 were studied with the aid of reflected light microscopy (Meijer Drees et al., 1995; Stasiuk 1999) and are composed of vitrinite, bituminite, sporinite, cutinite, *Botryococcus* alginite, fluorinite, acritarchs, calcareous microfossils, prasinophyte alginite, scolecodonts, and pyrite.

Killam Member

It has been shown before that the unit of bedded anhydrite in the lower part of the Shell Lake Member overlying the Winnipegosis Formation at Carruthers 10-11-45-23W3 (Fig. 11) changes westward into an interbedded unit of dolostone and anhydritic dolostone. Based on lithological criteria the interbedded unit belongs to the Winnipegosis rather than the Prairie Formation and it is proposed to name the bedded, evaporitic dolostone unit the Killam Member, after a small town in east-central Alberta.

The Killam Member is present at Elk Point 2-21-57-5W4 (Fig. 3) between approximately 1028.7 and 1039.3 m (3375–3410 ft.) and the upper part was cored. However, so little of the section is represented in the core boxes that it is proposed to define the Killam Member at Killam North 16-10-46-13W4 (Fig. 6). Here core recovery is excellent, and the interval between 1605.2 and 1609.2 m is proposed as the reference section.

Although the boundary between the Killam and Cutknife members is sharp and the intercalation of silty and anhydritic carbonates gives the Killam a characteristic signature on the gamma-ray curve, it is difficult to establish the boundary between the Killam and Cutknife members without detailed lithological information.

The boundary between the Killam Member and the Bawif Member is sharp and lies at the base of a 12 cm thick dolomitic claystone bed that forms a regional marker bed in east-central Alberta and southwestern Saskatchewan.

Stratigraphy and distribution

In east-central Alberta, north of the Meadow Lake Escarpment, the Killam Member forms the upper, silty and anhydritic part of the Winnipegosis carbonate shelf facies. It is 3.8 m thick at Chisholm 10-5-68-2W5 (Fig. 14) and 8.6 m thick at Venice 10-12-66-15W4 (Fig. 13). The anhydrite content in the Killam Member increases to the east, and in west-central Saskatchewan it grades laterally into the interbedded succession of light grey, laminated anhydrite mudstone, peloidal wackestone and nodular anhydrite of the upper part of the Shell Lake Member of the Prairie Formation (Meijer Drees, 1986).

Across the Red River subcrop ridge in east-central Alberta, the Killam Member extends southward across the onlap edge of the Cutknife Member but is truncated by, or has merged into, the overlying dolomitic claystone marker bed of the Bawif Member (Fig. 5). Thus, at Killam N 6-15-45-15W4 (Fig. 5, section 8) the Killam Member is present but at Strome 11-16-44-16W4 (Fig. 5, section 7) it is absent. The depositional limit of the member as shown on Figure 16 curves around the crest of the Red River subcrop ridge.

Lithology

In the reference section at Killam North 16-10-46-13W4 (Fig. 6) the member is a 4 m thick succession of interbedded light brown, dolomitic and silty, laminated, fine-peloidal pack- and grainstone, greyish brown anhydritic dolostone, minor nodular anhydrite, and many dark brown, bituminous shale partings. In the grainstone, the fenestral vugs and charophyte oogonia are cemented by halite or anhydrite. Also present are undulating stromatolites, intraclast breccia and moulds of halite crystals. The contact with the overlying greenish grey, dolomitic claystone marker bed of the Bawif Member is sharp and conformable. The contact with the underlying Cutknife Member is erosional and marked by a layer of pale, encrusted mudstone pebbles.

At Bruce 8-2-46-14W4 (Fig. 15) the Killam Member is 5 m thick and overlies the Cutknife Member with an erosional contact and a poorly sorted conglomerate. Here the interbedded lithological units are similar to those at Killam N 16-10-46-13W4 (Plate IIf) and the contact with the Bawif Member is erosional.

At Killam 15-34-43-10W4 (Fig. 9) the interbedded succession is 16.4 m thick and includes silty dolostone beds, porous grain- and packstone beds and greenish grey, dolomitic claystone beds. There is a hardground surface overlain by a dolostone conglomerate at 1464.2 m. The base of the succession is an erosional surface.

At Provost 11-35-38-10W4 (Fig. 8) the Killam Member is 8.7 m thick and was described by Meijer Drees et al. (1995) as an evaporitic facies unit of the Winnipegosis Formation.

At Luseland 16-36-36-25W3 (Fig. 17) the Killam Member is a 3 m thick, interbedded unit of laminoid-peloidal dolostone, fossiliferous dolostone including amphipora-like moulds cemented by halite, anhydritic dolostone, and light grey, nodular anhydrite. The upper boundary is erosional and lies below the dolomitic claystone marker bed of the Bawif Member.

At Venice 10-12-66-15W4 (Fig. 13) the peloidal dolostone succession is interbedded with greenish grey, dolomitic claystone that contains charophyte oogonia. Between 1146.3 and 1148.2 m (3761–3767 ft.) it includes several erosional surfaces overlain by claystone (Plate IIe). Here the contact between the Killam and Bawif members is overlain by a flat-pebble conglomerate.

At Chisholm 10-5-68-2W5 (Fig. 14) the Killam Member is 3.8 m thick. It is a nodular, interbedded succession of light brown, silty and anhydritic dolostone including charophyte oogonia, light brown, silty, laminated dolostone, greyish brown, calcareous dolostone, and greyish green very dolomitic claystone. The succession includes many dark brown, silty and carbonaceous shale partings. The lower contact with the fossiliferous limestone of the Cutknife Member is sharp and overlain by a 0.9 m thick, massive, greenish grey dolomitic siltstone bed. The upper contact with the Eyot Member is erosional (see Plate 2d).

Paleontology

A shale sample collected at Provost 11-35-38-10W4 (Fig. 8) at 1661 m (GSC loc. C-245072) yielded fragmentary spores of the Devonian (not older than late Eifelian) species *Geminospora lemurata* Balme emend. Playford. Carbonaceous shale samples in the Killam Member at Provost 11-35-38-10W4 are rich in terrestrial organic material (vitrinite, resinite, sporinite, cutinite) but also include laminated alginites, *Botryococcus* sp. and fragments of brachiopods, bryozoans, scolecodonts, chitinozoans, acanthomorphic acritarchs, *Tasmanites* and *Leiosphaeridia* (Fowler and Stasiuk 1998a; Stasiuk 1999).

A sample collected at 1454.7 m at Killam 15-34-43-10W4 (Fig. 9) also includes *Leiosphaeridia* sp. At Bruce 8-2-46-14W4 (Fig. 15) a dark grey, dolomitic shale bed at 1605.37 m (log depth 1606.87 m) includes ostracodes.

Geochemistry

In the basal part of the Killam Member at Killam 15-34-43-10W4 (Fig. 9), the carbonaceous shale layers contain between 5.21 and 24.33% TOC and have HI of between 61 and 197. The carbonaceous shale layers in the upper part include between 0.95 and 4.21% TOC with HI values between 316 and 563. The low HI values are indicative of Type III kerogen. The higher HI values are suggestive of Type II kerogen.

The TOC contents and the corresponding HI values of the shale beds in the Killam Member have been plotted on Figures 6, 8, 9, 13, 14, 15 and 17. They show the relationship between lithological and organic-geochemical information. Thus, high TOC content in the fossiliferous carbonate of the Cutknife Member are associated with Type II kerogen. The high TOC contents of the evaporitic carbonate of the Killam Member can be associated with Type II or III kerogen; the proportion of Type II organic matter increases upsection.

Sedimentology

The dolostone of the Killam Member does not include sedimentary structures related to wave- and current action. The fenestral (birdseye) voids, encrusted intraclasts and the charophytes in the peloidal pack- and grainstone are common attributes of carbonate accumulating in a restricted and evaporitic, shallow-water environment. The anhydrite nodules resemble those described from supra-tidal sabkhas, suggesting that the carbonate was exposed to evaporitic conditions after it was deposited.

The presence of spores, algae, ostracodes, and marine acritarchs in the carbonaceous samples of the Killam Member suggests that the organic material is derived from terrestrial, lacustrine and marine organisms. Meijer Drees et al. (1995) and Stasiuk (1999) recognized a marine organic paleoenvironment with a terrestrial influence, composed of laminated dolomite and including filamentous algae, spores and *Botyrococcus* algae.

Bawif Member

The proposed Bawif Member (named after a small town in east-central Alberta) forms the upper part of the Winnipegosis Formation in the marginal-marine carbonate shelf setting of southwestern Saskatchewan and east-central Alberta. It is composed of interbedded dolomitic shale, siltstone and anhydritic dolostone. Equivalent strata were previously mapped in east-central Alberta with the Shell Lake Member (Meijer Drees, 1994; Meijer Drees et al., 1995). In the proposed type section at Killam N 16-10-46-13W4 (Fig. 6) it is 11.2 m thick. Here it overlies the Killam Member as a 0.5 m thick, basal dolomitic claystone bed and underlies the salt deposits of the Leofnard Member of the Prairie Formation. The basal dolomitic claystone bed extends northeastward as an argillaceous marker bed at the top, or in the upper part of, the Shell Lake Member.

Stratigraphy

In the Red River subcrop region of east-central Alberta the basal claystone bed is overlain by an interbedded succession of dolomitic claystone, dolomitic siltstone, silty dolostone and anhydritic dolostone, which is in lateral interfingering contact with the interbedded succession of light grey, semitranslucent halite and light grey dolomitic anhydrite of the Leofnard Member (Meijer Drees, 1986). The anhydritic beds in the upper part of the Bawif Member continue upsection across the Meadow Lake Escarpment (Fig. 5) and across the Red River subcrop ridge (Fig. 12), replacing the overlying salt deposits.

In east-central Alberta, north of the Meadow Lake Escarpment, the interbedded succession is not present and here the basal claystone bed of the Bawif Member forms the uppermost unit of the Winnipegosis Formation (as at Elk Point 2-21-57-5W4, Fig. 3).

At Venice 10-12-66-15W4 (Fig. 13) the Bawif marker bed overlies the carbonate of the Killam Member with an erosional boundary. This erosional boundary can be traced along the Red River subcrop ridge. On Figure 5 the Killam Member is truncated between sections 10 and 11, and on Figure 12 the truncation is visible between sections 7 and 8.

The lateral facies relationship between the Bawif Member, the salt deposits of the Leofnard Member of the Prairie Formation and the Eyot Formation are schematically shown on Figure 4, suggesting that they are partly coeval. The erosional depression on the west side of the Red River subcrop ridge is filled with an interbedded succession of evaporitic carbonate, dolomitic siltstone, and halite (at Rich 7-25-34-21W4). This succession is mapped together with the Prairie Formation as an interbedded, transitional facies between the Eyot Formation and the Leofnard Member (see Fig. 5, section 4).

Regional distribution

The Bawif Member is widely distributed in east-central Alberta and southwestern Saskatchewan. The member reaches a maximum thickness of more than 14 m in east-central Alberta. Here it grades southwestward into the lower part of the Eyot Formation. The southwestern limit of the member coincides with the boundary between the Prairie and Eyot formations (Fig. 4).

In southwestern Saskatchewan (Fig. 10) and northeastern Alberta (Meijer Drees, 1985, fig. 53), the shaly equivalent of the basal Bawif Member extends eastward beyond the eastern limit of the Killam Member and forms a shaly unit between the Shell Lake Member and the salt deposits of the Leofnard Member (Fig. 4). This shaly unit may continue beyond the northeastern depositional edge of the Cutknife Member into the upper part of the "undifferentiated Shell Lake - Whitkow", a unit composed of interbedded anhydrite mudstone, peloidal wackestone, and nodular anhydrite, which includes (at Battle River 7-30-43-16W3 and Hamil Prov 1-29-45-16W3) erosional surfaces overlain by greenish grey, anhydritic shale or conglomerate (Meijer Drees, 1986, figs. 54g and d).

Lithology

At Killam North 16-10-46-13W4 (Fig. 6) the Bawif Member is present between 1605 and 1594 m (core depths 1592.4 and 1603.7 m). The lower part of the member is composed of dark greenish grey, dolomitic claystone, which is, in the upper part, interbedded with carbonaceous partings including plant fragments and ostracodes. The upper part of the member is an interbedded succession of greenish grey dolomitic claystone, light brown, silty and anhydritic dolostone, and dolomitic siltstone. The light brown dolostone beds are very fine- to fine-peloidal wacke- and packstone and include charophyte oogonia and dark carbonaceous shale layers. Sedimentary features commonly seen include scoured surfaces overlain by mudclasts; fenestral vugs cemented by halite or anhydrite, anhydrite nodules, and irregular vugs and fractures filled with halite (Plate 1g).

The Bawif Member is 12.5 m thick at Provost 11-35-38-10W4 (Fig. 8), including the 1.46 m thick marker bed. The marker bed and the overlying strata include rock types similar to those at Killam N 16-10, but the greenish grey, dolomitic claystone beds are dominant in the upper part.

At Venice 10-12-66-15W4 (Fig. 13) the Bawif Member is 6.8 m thick. Here the marker bed overlies a thin conglomerate composed of angular fragments of dolostone, similar to the dolostone of the underlying Killam Member. In the cored interval the upper part of the member is an interbedded succession of massive, greyish green, silty and dolomitic claystone, light greyish brown dolostone and greyish brown, anhydritic dolostone. The claystone beds have a massive, bioturbated aspect. The dolomitic intervals are interlaminated mud- and fine-peloidal grainstone, including scoured surfaces, mudclasts and desiccation fractures. The vuggy and fracture porosity is cemented by halite. At Beaverhill Lake 11-11-50-17W4 (Fig. 2, loc. 21) the Bawif Member includes several fossiliferous dolostone interbeds. Here the leached gastropods and ostracodes are filled with halite.

In the cored section at Luseland 16-36-36-25W3 (Fig. 17), the Bawif is a 0.3 m thick greenish grey and dark grey, mottled, dolomitic and silty claystone that is in erosional contact with the underlying Killam Member and includes mudstone pebbles. Overlying the marker is a 9 m thick, interbedded succession of light brown and greyish brown, very fine- to fine-crystalline dolostone, grey, nodular anhydrite, light grey, dolomitic anhydrite, and greyish brown to dark greyish brown dolostone containing very dark brown shaly partings.

At Elk Point 2-21-57-5W4 (Fig. 3) the Bawif Member is represented only by the basal marker bed. It is 2.7 m thick and composed of light brown and light greenish grey, halite-impregnated, dolomitic siltstone, in part interbedded with halite and dark grey, carbonaceous shale rich in charophyte oogonia and halite crystals (such as shown in Plate 1g).

Paleontology

At Spiers 11-15-34-15W4 (Fig. 12, section 6) basal Devonian clastic rocks included within the Bawif Member contain crinoidal debris. A sample at 1923.67 m (just above the pre-Devonian unconformity) includes conodonts of the long-ranging genus *Panderodus*. A sample at 1921.69 m yielded an extraordinarily diverse reworked conodont fauna including species representing several Early Ordovician stages (Hein and Nowlan, 1998). One of the carbonaceous shale layers located just below the Leofnard salt beds (1914.75 m; GSC loc. C-245046) yielded trilete spores including *Geminospora lemurata* Balme emend. Playford and *Contagisporites optivus* (Chibrikova) Owens var. *optivus*. The assemblage indicates probable correlation with the lower *optivus-triangulatus* Zone of Richardson and McGregor (1986) and an age not older than mid-Givetian. A carbonaceous shale at 1785.33 m in Strome 8-23-43-16W4 (Fig. 3, section 6) includes *Botryococcus* alginite, acanthomorphic acritarchs, and miospores. A sample at 1789.05 m in the same location contains spores and leiospheres.

At Provost 11-35-38-10W4 (Fig. 8) a sample at 1652.12 m (GSC loc. C-252431) contains poorly preserved trilete spores of land plants and abundant leiospheres, presumably of aquatic algae. A microscopic study of the carbonaceous material of the Provost 11-35-38-10W4 shale samples indicates the presence of laminated alginite and, locally, remains of spores, acritarchs, *Leiosphaeridia*, and *Tasmanites* (Stasiuk, 1999).

Middle Devonian, probably Givetian spores of land plants including, among others, *Grandispora velata*, ?*Geminospora lemurata*, *Ancyrospora* sp., and two new species of *Emphanisporites* were obtained from a sample of the basal dolomitic claystone bed at 1139.1 m (3737.5 ft.; GSC locality C-252339) at Venice 10-12-66-15W4 (Fig. 13).

Geochemistry

The TOC of carbonaceous shale layers in the Bawif Member at Killam North 16-10 (Fig. 6), Provost 11-35-38-10W4 (Fig. 8) and Venice 10-12 (Fig. 13) ranges between 0.37 to 9.56% and the HI between 138 and 654. The TOC of the carbonaceous shale interbeds at Luseland 16-36-36-25W3 (Fig. 17) ranges between 0.19 and 14.9% and the HI between 25 and 569. A shale sample at 1420 m (TOC 7.92, HI 351) includes a mixture of terrestrial plant spores and remains of algae (Fowler and Stasiuk 1998b). The high hydrogen indices (more than 500) are indicative of Type II kerogen, which may have come from algal mats or planktonic algae.

Sedimentology

The small-scale sedimentary structures characteristic of alternating dry and wet environments of deposition (such as small-scale erosional surfaces overlain by mudstone clasts, fenestral vugs cemented by anhydrite or halite, and stromatolitic laminae) are deformed by compaction and anhydritization. These structures and the sabkha-like anhydrite nodules and cubic moulds of halite crystals suggest an environment of deposition under evaporitic conditions.

Meijer Drees et al. (1995, Fig. 4) and Stasiuk (1999) provided a summary of the vertical changes seen in some of the carbonaceous shale layers at Provost 11-35-38-10W4. They described an interbedded succession of organic-rich layers composed of laminated anhydrite and dolomite including filamentous alginite stromatolites; and organic-lean layers composed of nodular anhydrite, dolomite, and clay including acritarchs and minor filamentous alginite.

Eyot Formation

The Eyot Formation was introduced in central Alberta (Meijer Drees, 1994) to designate the westward thinning wedge of marginal, interbedded, shaly, silty, dolomitic and anhydritic deposits equivalent to the Leofnard salt deposits of the Prairie Formation. It is proposed to define the Eyot as a formation that overlies either the Killam Member of the Winnipegosis Formation, or the pre-Devonian unconformity in places beyond the depositional margin of the Winnipegosis. The name of the formation is derived from the Imperial Eyot No. 1 borehole, located at 3-28-48-25W4 in central Alberta (Fig. 18, section 4). This borehole includes the proposed type section of the Eyot Formation between 2192.4 and 2257 m (7193–7405 ft.). Here the formation overlies the Winnipegosis Formation and underlies the Watt Mountain Formation.

It is proposed to define the upper boundary of the Eyot Formation at the base of the Watt Mountain Formation or the lower red bed member of the Dawson Bay Formation. This boundary is marked on borehole logs by a fairly sharp upward decrease in resistivity and an associated increase in radioactivity caused by a decrease in anhydrite and dolomite content in the succession. In places this change is accompanied by an upward change in colour from greyish green to mottled green and reddish brown, or it is marked by the presence of an erosional surface.

In central Alberta (Fig. 18) the lower boundary of the Eyot Formation is selected at the contact between light greyish brown dolostone (Winnipegosis) and dark grey

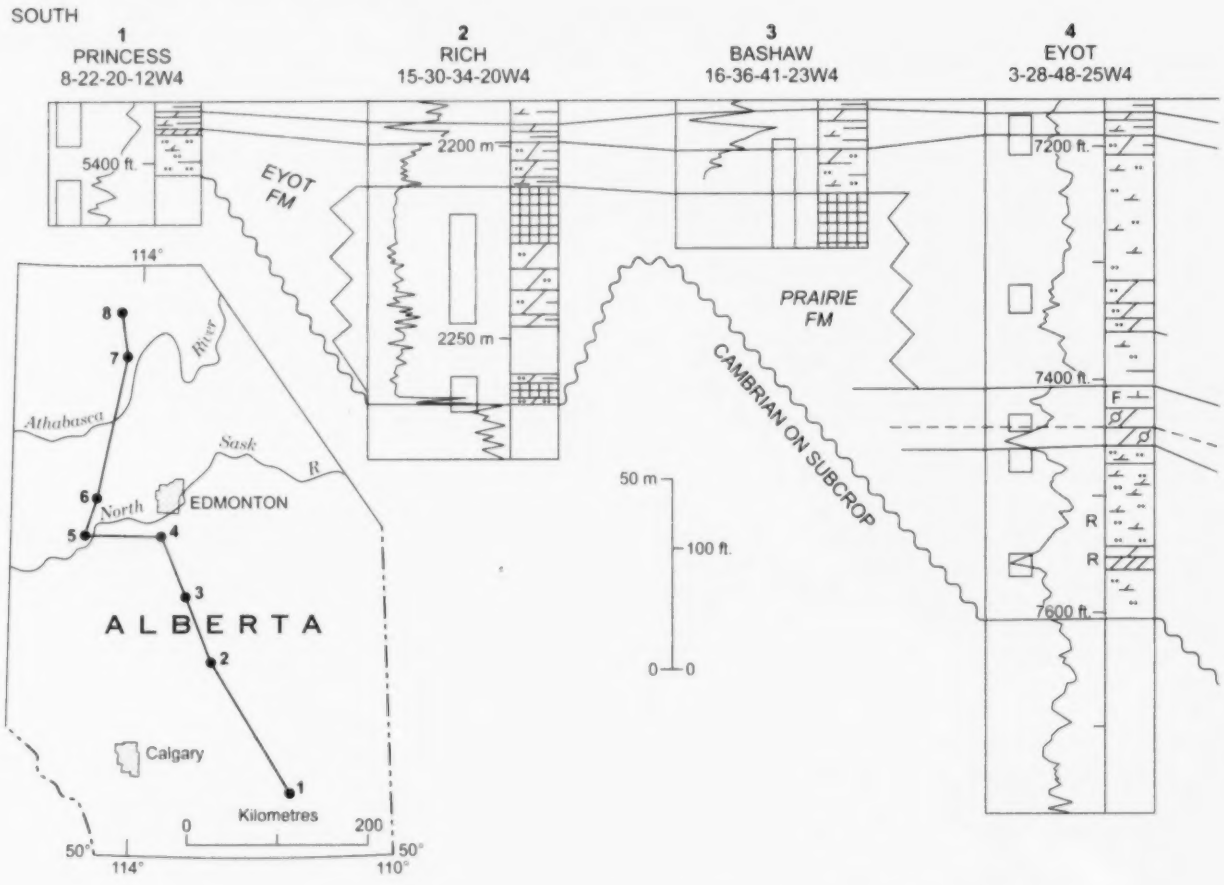


Figure 18. *North-to-south stratigraphic cross-section including the Eyot Formation.*

dolomitic siltstone or silty and dolomitic shale (Eyot). In west-central Alberta the lower boundary coincides with the pre-Devonian unconformity.

Stratigraphy

The Eyot Formation includes lower and upper parts. The lower part passes laterally into the Bawif Member (Fig. 12, 18). The upper part is in lateral contact with the salt deposits of the Leofnard Member, and in the zone of interfingering (Fig. 12, 18) the Eyot Formation overlies the Prairie Formation.

Regional distribution

The Eyot Formation is widely distributed in southern and central Alberta between the depositional limit of the Elk Point Group in the west and the depositional limit of the salt deposits in the east (see Fig. 16).

Lithology

In the type section at Eyot 3-28-48-25W4 (Fig. 18, sec. 4) the lower part of the formation (interval 2247.9–2257 m, 7375–7405 ft.) consists of greenish grey, dolomitic and anhydritic shale. The upper part (interval 2192.4–2247.9 m, 7193–7375 ft.) is an interbedded succession of dark greenish grey to dark grey, dolomitic shale, greyish brown, argillaceous, silty and anhydritic dolostone, in part with a fine peloidal aspect, and pale greenish grey and greenish grey, argillaceous siltstone.

The lower part of the formation was cored at Imperial Buck Creek 14-29-48-6W5 (Fig. 18, sec. 5) and consists of dark greenish grey, silty shale that includes scattered fragments of small brachiopod shells, fish remains and charophyte oogonia. Two thin, calcareous coquina beds occur between 9779 and 9779.5 ft. in a silty shale.

The lower part and the contact with the Winnipegosis were also cored at Chisholm 10-5-68-2W5 (Fig. 14). Here a

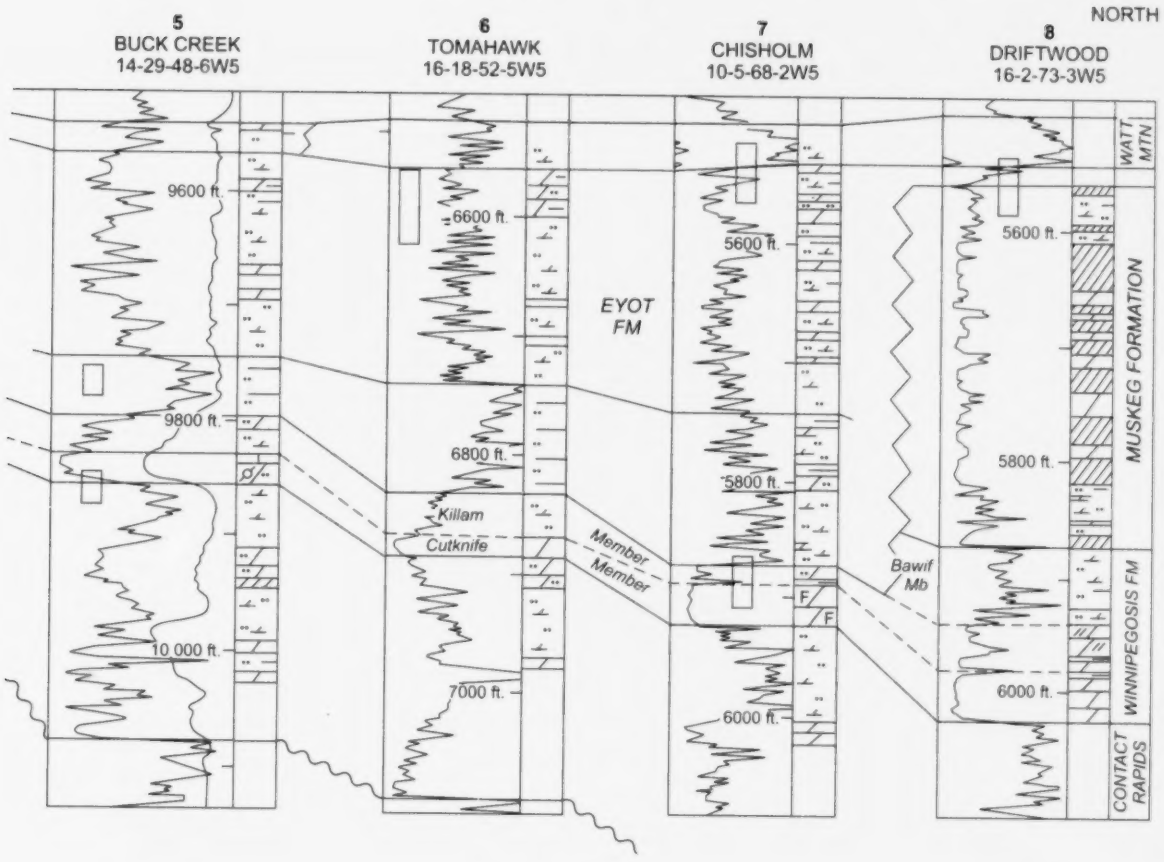


Figure 18 continued.

basal, greyish green, dolomitic siltstone bed (0.6 m thick) overlies an erosional surface (Plate 2d) and is overlain by a dark greyish green, silty claystone bed that includes an abundance of calcareous charophyte oogonia and fragments of placoderm fish.

A cored interval in the middle part of the Eyot Formation at Eyot 3-28-48-25W4 (Fig. 18, sec. 4) consists of thinly interbedded silty and argillaceous dolostone and very dark greenish grey, dolomitic shale. The dolostone beds have a fine peloidal aspect and contain charophyte oogonia and fenestral vugs cemented with anhydrite.

The upper part of the Eyot Formation was cored at Chisholm 10-5-68-2W5 (Fig. 19), Bashaw 16-36-41-23W4 (Fig. 20), Tomahawk 16-18-52-5W5 (Fig. 21), and Princess CPR 14-22A 8-22-20-12W4 (Fig. 22). In these sections the Eyot is a thinly interbedded succession of dark greenish grey, dolomitic shale, greenish grey dolomitic and silty claystone, greyish brown, dolomitic and locally anhydritic claystone, and minor, grey anhydrite. At Princess CPR 14-22A, 8-22 20-12W4, the upper boundary is indicated by an erosional surface.

The anhydritic and dolomitic beds are generally laminated and have a peloidal or stromatolitic aspect. They are commonly overlain with an erosional contact by thin, dark grey, carbonaceous shale beds. The greenish grey, dolomitic shale beds overlie either the carbonaceous shale beds or the greyish brown dolostone beds with a sharp contact. The greenish grey dolomitic shale beds commonly grade upward into silty and dolomitic claystone that has a massive, bioturbated aspect. The massive claystone beds locally grade upward into massive anhydrite through an interval containing anhydrite nodules. At many places the vertical succession of these four rock types is incomplete so that only two or three alternate. The boundary between the Eyot and the underlying salt deposits of the Leofnard Member at Bashaw 16-36-41-23W4 (Fig. 20) is sharp and marked by the presence of displacive, nodular halite deposits in a matrix of peloidal, stromatolitic and anhydritic dolostone beds. The boundary with the overlying dolomitic

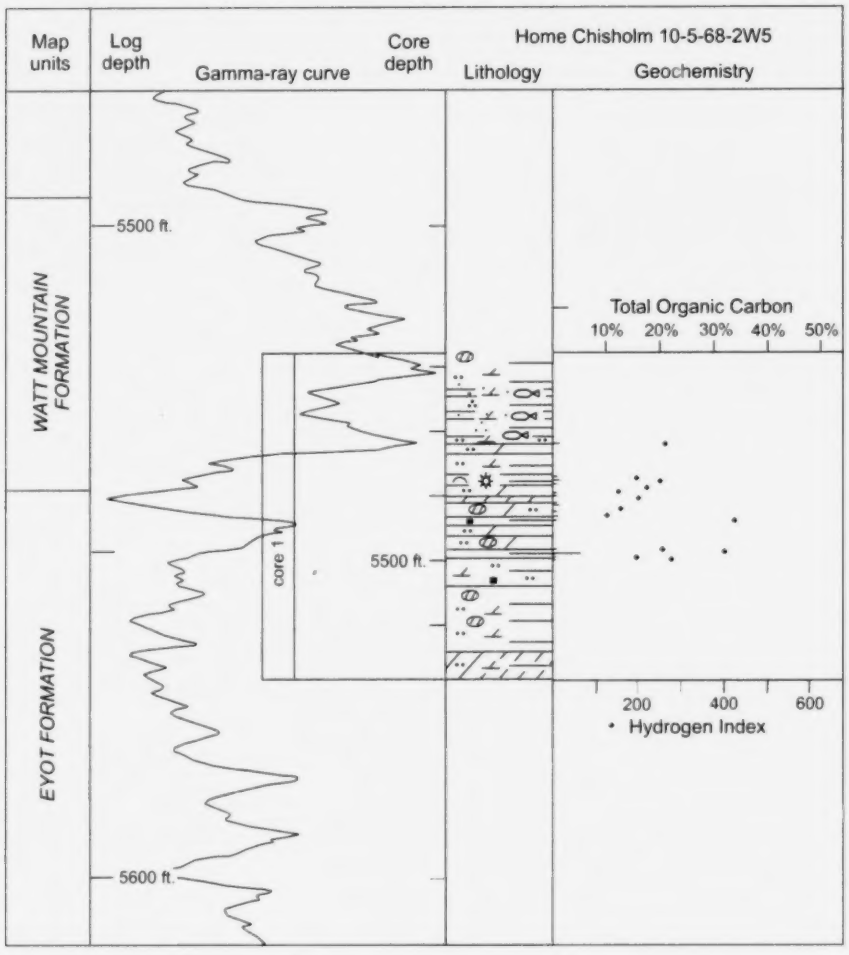


Figure 19. *Geophysical, lithological, and geochemical diagram of Middle Devonian strata at Home et al. Chisholm 10-5-68-2W5.*

claystone beds of the Watt Mountain Formation is selected at 2261.6 m, above a burrowed surface, overlain by a reddish brown-stained layer that includes anhydritic silt lenses and mudclasts.

At Chisholm 10-5-68-2W5 (Fig. 19) two very dark greenish grey shale beds in the upper part of the Eyot Formation include fragments of small lingulid brachiopods and placoderm fish bones.

The boundary with the Watt Mountain Formation lies at the top of an interbedded interval of silty dolostone, dark grey shale and grey anhydrite. At Princess CPR 14-22A 8-22-20-12W4 (Fig. 22) only the uppermost part of the Eyot Formation was cored. A thin-bedded and irregularly laminated succession of nodular, greenish grey dolomitic siltstone and dark greyish brown shale is overlain by a 0.8 m thick nodular-bedded anhydrite that includes a greyish green, silty claystone matrix.

Paleontology

Trilete spores of probable Givetian age occur in a number of samples at Bashaw 16-36-41-23W4 (Fig. 20). The samples at 2664.17 m (GSC loc. C-245270), 2273.34 m (GSC loc. C-245286), and 2282.65 m (GSC loc. C-245297) together include the following species: *Aneurospora goensis* Streel, *Archaeozonotriletes variabilis* Naumova, *?A. violabilis* Chibrikova, *Emphanisporites* nov. sp., *Geminospora* sp., *?Grandispora longa* Chi and Hills, *Perotrilites ergatus* Allen, *Rhabdosporites langii* (Eisenack) Richardson 1960, and *Verrucosisporites scurrus* (Naumova) McGregor and Camfield. A spore assemblage from 2274.9 m (GSC loc. C-245290) contains *Contagisporites optivus* (Chibrikova) Owens var. *optivus*, indicating a late Givetian age.

Givetian spores were also recovered at Tomahawk 16-18-52-5W5 (Fig. 21) from samples at 8569.75 ft. (GSC loc. C-245303), 8570.16 ft. (GSC loc. C-245304), 8578 ft.

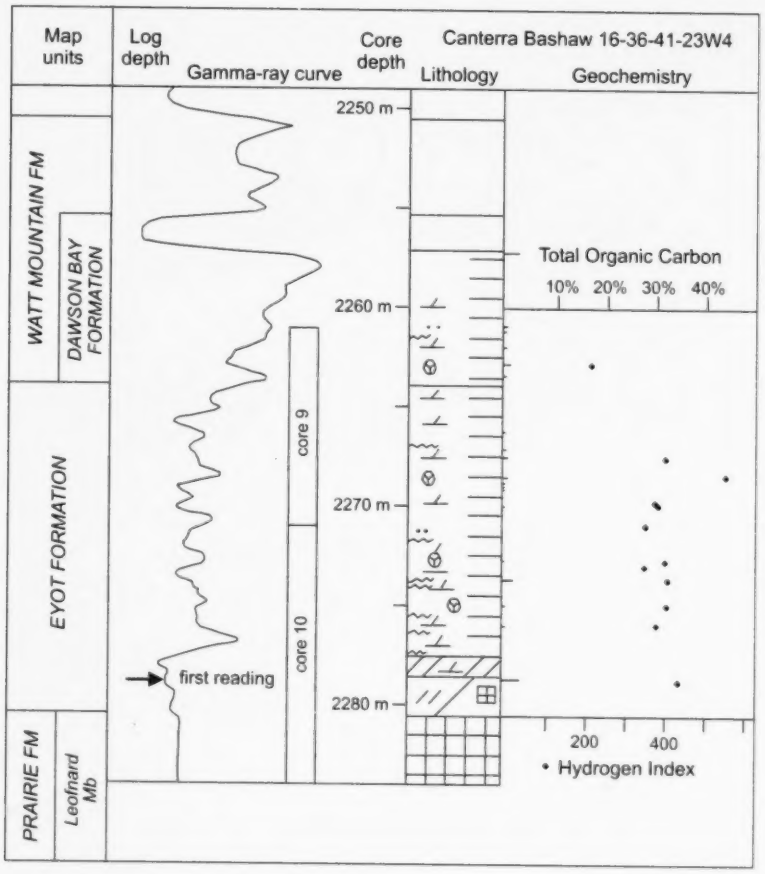


Figure 20. *Geophysical, lithological, and geochemical diagram of Middle Devonian strata at Canterra Bashaw 16-36-41-23W4.*

(GSC loc. C-245310), 8584.33 ft. (GSC loc. C-245314) and 8572.58 ft. (GSC loc. C-245317). They include the following species: *Aneurospora goensis* Streel, *Archaeozonotriletes variabilis* Naumova, *A. timanicus* Naumova, ?*A. meandricus* Allen, ?*A. violabilis* Chibrikova, *Chelinospora* sp., *C. concinna* Allen, ?*Costazonotriletes* nov. sp., ?*Cristatisporites triangulatus* (Allen) McGregor and Camfield, *Emphanisporites* nov. sp., *Hystricosporites* sp. and *Geminospora* sp. (Plate 3).

The shell fragments found at Chisholm 10-5-68-2W5 (Fig. 19), just below the top of the formation, are probably ostracodes (Nowlan, 1998b).

A shale sample at 691.59 m (2269 ft.; GSC loc. C-245118) in a succession of interbedded dolomitic claystone and silty dolostone equivalent to the Eyot Formation at Virago et al. Rich 15-30-34-20W4 (Fig. 2, section 4) includes anchor-spined spores and specimens of *Grandispora velata* (Eisenack) Playford of terrestrial origin.

The presence of spores and absence of marine microfossils other than ostracodes suggests that most, if not all, of the organic material in the Eyot is of nonmarine origin.

Geochemistry

The thin, carbonaceous shale interbeds and partings at Tomahawk (Fig. 21) include up to 1.23% TOC and the HI values range between 176 and 580. At Bashaw they include up to 2.55% TOC and the HI values fall between 231 and 555 (Fig. 19). At Chisholm 10-5-68-2W5 many of the dark grey shale beds contain only between 0.5 and 1.5% TOC, and HI values range between 120 to 428 (Fig. 20).

The paleontological information on the organic matter in the Eyot Formation suggests that it was largely derived from terrestrial plants.

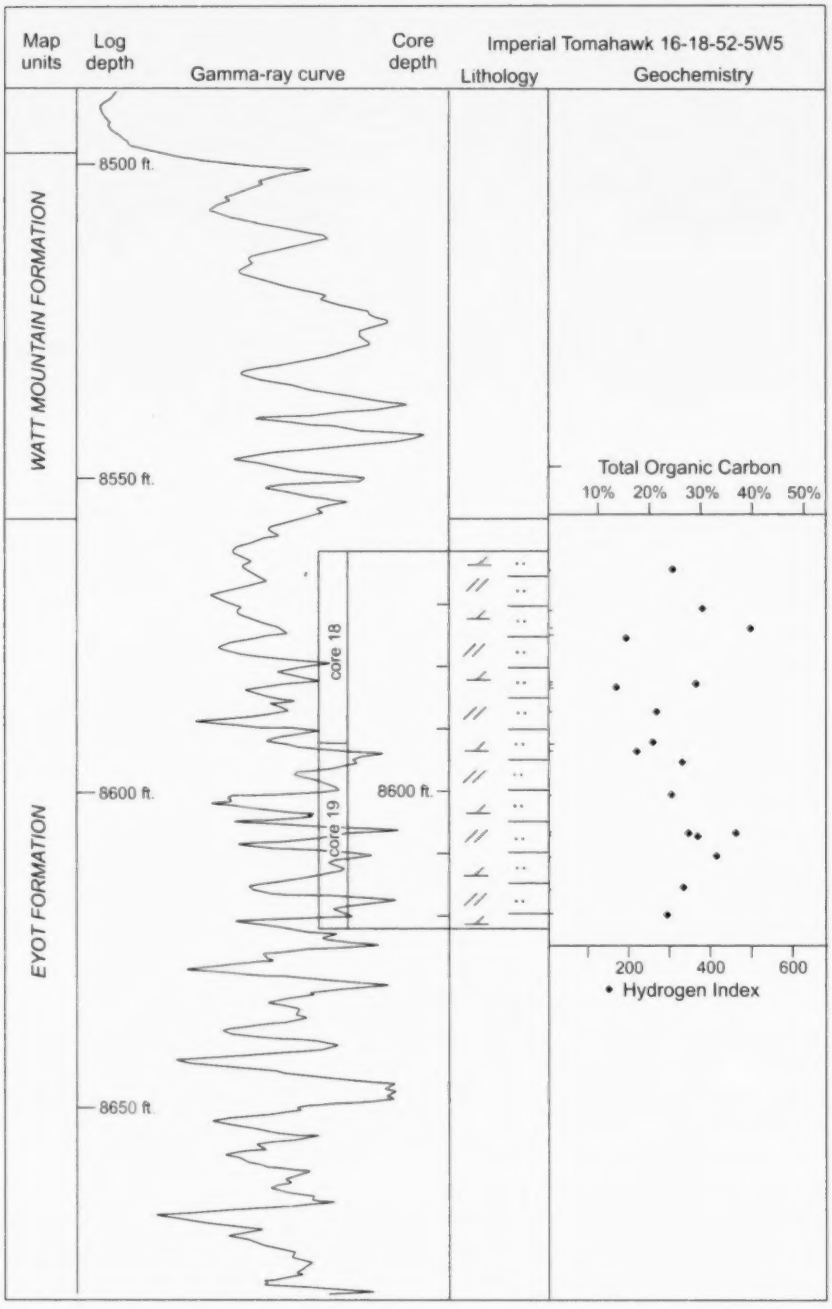


Figure 21. *Geophysical, lithological, and geochemical diagram of Middle Devonian strata at Imperial Tomahawk 16-18-52-5W5.*

Sedimentology

The lithological units and sedimentary structures in the Eyot Formation are similar to those of the Bawif Member of the Winnipegosis Formation. The dolomitic claystone beds have a massive, bioturbated aspect, but do not include recognizable burrows. The dolostone beds comprise laminated mudstone or peloidal wackestone, and include scoured surfaces, mudclasts, deformed moulds of halite crystals and fenestral vugs cemented by anhydrite.

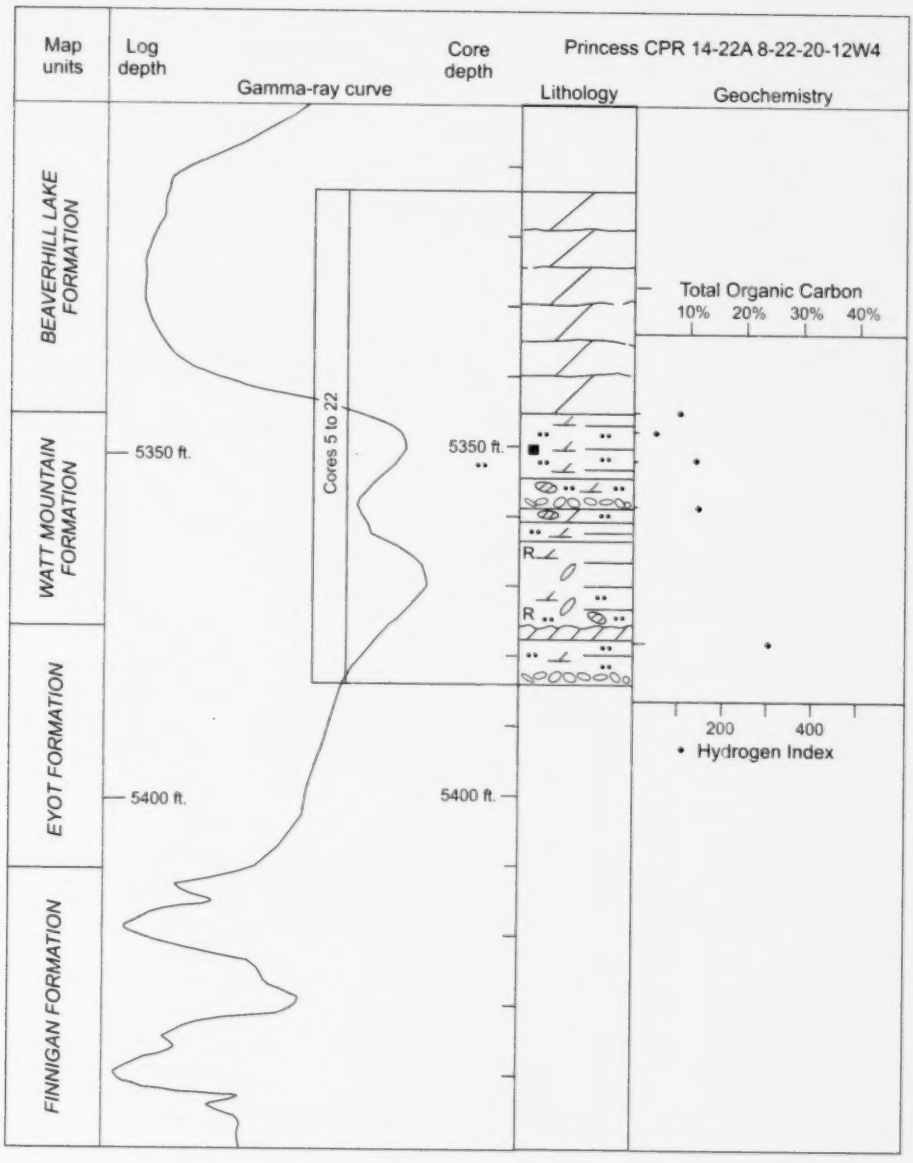


Figure 22. *Geophysical, lithological, and geochemical diagram of Middle Devonian strata at Princess CPR 14-22A, 8-22-20-12W4.*

Similar rock types were also reported from an unnamed shale unit that underlies the Leofnard Member at Bat Lake 6-31-84-7W5 and from the upper part of the Muskeg Formation at Driftwood 10-12-73-3W5 (Meijer Drees, 1986, figs. 59a,d, 61d,e,e). Here peloidal wackestone includes remains of calcareous algae.

The mudstone and carbonate wackestone probably accumulated in an alternating dry and wet, highly saline and shallow-water environment.

INTERPRETATION OF DEPOSITIONAL ENVIRONMENTS

Perrin (1982) considered the Ashern Formation in North Dakota to represent the deposits of an early Devonian transgression and noted the presence of a regressive phase at its top. The Middle Devonian transgression was initiated after this regressive phase and includes two episodes. During the first episode, carbonate of the lower part of the Winnipegosis Formation accumulated in a marine, subtidal

environment. During the second episode, the Elk Point Basin differentiated into shallow-shelf and deeper basin regions and the upper part of the Winnipegosis Formation was deposited. In the shelf region the accumulation of shallow-marine, subtidal carbonate continued and was augmented by patch reef, lagoonal and tidal-flat deposits. In the deeper basin the carbonate include the "Pinnacle Reefs" and "Laminated Mudstones" deposits.

According to Perrin (1982) the "Coral Stromatoporoid Packstone" deposits of the carbonate shelf and the "Crinkly Stromatolite" deposit on the "Pinnacle Reefs" represent a minor regression that was also responsible for the diagenetic changes (leaching and pervasive dolomitization) in the reef interior.

The dark, "Laminated and Mottled Dolomite Mudstone" deposit that overlies the "Crinkly Stromatolite" deposit is also present on the shelf and may represent a minor transgressive phase.

After this transgressive phase sea level fell substantially (Perrin, 1982). Deposits of "Redbeds" formed on top of the pinnacle reefs and a diagenetic "Pisolite Dolomite" facies formed within the exposed "Pinnacle Reefs". Coeval deposits in the shallow inter-reef environment include organic-rich algal mat deposits (the "Golden Stromatolite" facies), overlain by dark, "Laminated and Mottled Dolomite Mudstone" deposits.

The idea that sea level fell in the Elk Point Basin originated from the recognition that the nodular anhydrite in the "laminites" of the Ratner Member is similar to the diagenetic anhydrite nodules found in the sabkhas of the Persian Gulf (Fuller and Porter, 1969; Shearman and Fuller, 1969). Thus Bebout and Maiklem (1973) postulated a significant drop in the Middle Devonian sea level after the formation of the Pinnacle Reefs deposits. They suggested that this relative drop in sea level turned the Elk Point Basin into a saline lake. A subsequent slow relative rise in Middle Devonian sea level caused periodic marine invasions and, through the process of "evaporite draw-down" (Maiklem, 1971), each invasion left a new deposit of evaporite in the Elk Point Basin, until it was filled to the original height of the Presqu'ile Barrier.

During the period of low water stand (Lowstand Systems Tract) the carbonate shelf must have been exposed and subjected to dissolution, diagenesis and erosional incision. Erosional products of the hinterland and the desiccated shelf must have been transported to the shelf edge by occasional rainstorms and accumulated as a narrow wedge at the foot of the shelf edge (see Van Wagoner et al., 1988; Sarg, 1988; James and Kendall, 1992).

The data obtained from east-central Alberta and west-central Saskatchewan show that the basal Devonian carbonate-rich clastic rocks of the Ashern Formation onlap the pre-Devonian unconformity and change laterally into carbonate of the Winnipegosis Formation (Fig. 4). Here the Ashern Formation represents a basal transgressive deposit that ranges in age from early to late Middle Devonian.

The distribution, thickness and facies relationships between the Ashern and the Eyehill, Cutknife, and Killam members of the Winnipegosis Formation (Fig. 4) suggest that the Eyehill Member along the western margin of the basin can be classified as a subtidal, landward-migrating deposit formed during the initial phase of the early Middle Devonian transgression (the Transgressive Systems Tract of Van Wagoner et al. 1988; Sarg, 1988). The Cutknife and Killam members form a wedge of shelf carbonate including slope deposits (lower part Cutknife), upper shelf deposits (upper part Cutknife), and peritidal mudflat or sabkha deposits (Killam). The carbonate wedge may have accumulated during the Middle Devonian by progradation during a sea-level highstand when basinal sediments (Brightholme Member) were deposited in the central part of the basin. The presence in the Killam Member of sabkha deposits, anhydritized and dolomitized sediments, and the presence of equivalent halite deposits on the west side of the Red River subcrop ridge suggest that during and after the highstand in the Elk Point embayment the water along the shelf edge and possibly on the shelf itself had become enriched in magnesium, sulphate and sodium chlorite.

The Killam Member of the Winnipegosis Formation is overlain and locally truncated by an erosional surface. This surface may have formed after the postulated fall of the Middle Devonian sea level. If it can be demonstrated that the erosional surface continues basinward across the carbonate shelf into the "undifferentiated Shell Lake-Whitkow" unit (Fig. 4), the overlying halite-impregnated, anhydritic siltstone of the Bawif Member could be part of a Lowstand Systems Tract wedge that accumulated after the postulated fall. The laminated and nodular anhydritic carbonate of the Ratner Member and the salt deposits of the Whikow Member could have formed after the sea level fall and could represent Lowstand Systems Tract deposits in the central part of the basin.

The stratigraphic relationships between the Bawif Member of the Winnipegosis Formation and the Leofnard Member of the Prairie Formation illustrated in Figure 4 suggest that the basal part of the Bawif Member represents a basal transgressive deposit that overlies a hiatus in deposition marked by minor erosion and extensive dolomitization and anhydritization of the underlying shelf carbonate. One may thus argue that the Bawif Member

belongs stratigraphically with the Whitkow, Shell Lake, and Leofnard members, and that the Bawif Member and the Eyot Formation are part of a transgressive sequence of sulphate, carbonate-rich clastic rocks and evaporite deposits that accumulated after the postulated Middle Devonian fall in sea level.

CONCLUSIONS

The Middle Devonian succession in east-central Alberta and west-central Saskatchewan unconformably overlies the Cambrian and Ordovician strata and in places onlaps the Red River subcrop ridge along the Ordovician subcrop edge. This ridge continues northeastward into the Meadow Lake Escarpment.

The stratigraphy across the ridge, summarized in Figure 4, suggests that the Middle Devonian succession along the western margin of the Elk Point Basin includes a basal transgressive deposit that onlaps the pre-Devonian unconformity (Ashern Formation). The basal clastic rocks are overlain by a shelf-like wedge of carbonate, which is part of the Winnipegosis Formation. In Alberta this formation includes a lower, in part transgressive, shaly facies, fossiliferous ramp facies, and marginal evaporitic facies, and an upper, silty and anhydritic facies. The upper two facies are not part of the upper member of the Winnipegosis Formation in the central and eastern parts of the Elk Point Basin. Thus it is proposed to introduce in Alberta a subdivision in formally defined members.

In ascending order the new members are the Eyehill, Cutknife, Killam, and Bawif. The Eyehill Member is in mappable continuity with the lower Winnipegosis member of southern Saskatchewan and extends westward into east-central Alberta. The Cutknife is in mappable continuity with the upper Winnipegosis member of southwestern Saskatchewan and extends westward beyond the depositional limit of the Eyehill. The member is difficult to separate from the overlying Killam Member without good lithological information. To the east, both the Killam and the Bawif members are in lateral facies contact with the upper part of the Shell Lake Member of the Prairie Formation and extend westward into east-central Alberta beyond the depositional limit of the Eyehill Formation. The depositional limits of some of the members are shown on Figure 16.

The lithological information from the borehole sections of the Ashern and Winnipegosis formations are summarized on the diagrams. The Middle Devonian succession includes several interbedded lithological units and changes character in an orderly fashion from the base upward. The pre-Devonian unconformity is overlain (in ascending order) by argillaceous and silty beds, argillaceous and fossiliferous carbonate, evaporitic carbonate, shaly and silty carbonate-rich anhydrite, and halite. The succession forms a "shallowing-upward sequence" that changes character from marginal-marine to normal-marine and evaporitic.

The Bawif Member overlies the Killam Member, or locally the Cutknife, with an erosional contact. This erosional contact is overlain by a siltstone marker bed that can be traced eastward into the upper part of the Shell Lake Member. The Bawif Member underlies salt deposits of the Prairie Formation and grades westward into the lower part of an interbedded succession of shaly and silty deposits that represent the marginal nearshore facies of the halite deposits. These marginal clastic deposits belong to the (newly defined) Eyot Formation. The stratigraphic relationships between the Bawif Member, the Eyot Formation and the Prairie Formation suggest that the basal siltstone bed of the Bawif Member represents a basal transgressive deposit and that the Bawif Member belongs to the evaporitic succession of the Prairie Formation.

The Middle Devonian succession includes many thin shale beds (0.1–1 cm thick) that were analyzed for their total organic carbon content by Rock-Eval pyrolysis. The combination of relatively high TOC values and low HI values (less than 150) are indicative of Type III kerogen, while relatively high HI values (more than 300) indicate the presence of Type II kerogen. Values of more than 700 indicate the presence of Type I kerogen.

The data from the Elk Point Group indicate that the shale samples of the marginal-marine Ashern Formation and the marine Eyehill Member are characterized by relatively low TOC values and low HI values. The shale of the marine Cutknife Member includes low and high TOC values and relatively low HI values, while those of the evaporitic Killam and Bawif members include both low and high TOC values and low and high HI values. Thus the carbonaceous material in the shale beds associated with marginal-marine and marine carbonate deposits contains mostly Type III kerogen, and that in the anhydritic carbonate includes Type II and Type III kerogens.

Several of the carbonaceous shale samples yielded well-preserved spores and other microfossils. Spores diagnostic of the Givetian Stage were obtained from the Ashern, Winnipegosis, and Eyot formations. The Cutknife Member includes *Stringocephalus* brachiopods, also diagnostic for the Givetian.

Many of the carbon-rich shale samples were studied by means of incident light microscopy, using white- and fluorescent light sources, in order to reveal the nature of the organic material.

Two coaly shale samples, collected in the Ashern Formation, just above the pre-Devonian unconformity, contain spores of Middle Devonian land plants. The spores probably accumulated in a lacustrine environment. Other carbonaceous shale samples in the upper part of the Ashern Formation include filamentous alginite (resembling *Botryrococcus* sp. and *Gloeocapsomorpha prisca*), *Veryachium* type acritarchs, *Leiospheridia*, and *Tasmanites*. These organic remains are indicative of a semirestricted, marginal-marine or lagoonal environment.

The shale samples collected in the Eyehill Member of the Winnipegosis Formation do not contain enough carbonaceous material to warrant studying its nature.

Some of the organic material in the carbon-rich samples from the Cutknife Member in the Sakatchewan boreholes and in the Marwayne 14-29-52-2W4 borehole in Alberta is dominated by spore fragments of land plants. Other carbon-rich layers contain remains of filamentous algae. The organic material in the carbon-lean samples is associated with remains of ostracodes, scolecodonts and acritarchs. The presence of lagoonal- and terrestrial-derived organic material in the shallow-marine environment suggests that the it was transported to the shelf by wind and water.

The carbon-rich shale in the Killam and Bawif members includes much terrestrial material (vitrinite, resinite, sporinite, cutinite) but also includes remains of marginal-marine plants and animals (alginites, acritarchs, chitinozoans, bryozoans, scolecodonts, ostracodes).

The shale samples collected in the Eyot Formation contain only 0.5 and 2.55% TOC. The presence of many spores and minor amounts of alginite suggest that the carbonaceous matter is of terrestrial origin.

REFERENCES

Baillie, A.D.

1950: Devonian geology of Lake Manitoba-Lake Winnipegosis area; Manitoba Mines Branch, Publication 49-2.

1951: Devonian geology of Lake Manitoba - Lake Winnipegosis area; Manitoba Mines Branch Publication 49-2.

1953a: Devonian System of the Williston Basin area; Manitoba Mines Branch, Publication 52-5.

1953b: Devonian names and correlation in the Williston Basin; American Association of Petroleum Geologists, Bulletin, v. 37, p. 444–452.

Bebout, D.G. and Maiklem, W.R.

1973: Ancient anhydrite facies and environments, Middle Devonian Elk Point Basin, Alberta; Bulletin of Canadian Petroleum Geology, v. 21, p. 287–343.

Belyea, H.R.

1959: Devonian Elk Point Group, central and southern Alberta; Geological Survey of Canada, Paper 59-2.

Crickmay, C.H.

1954: Paleontological correlation of Elk Point and equivalents; *in* Ralph Leslie Rutherford Memorial Volume, Western Canada Sedimentaty Basin, (ed.) L.M. Clark; American Association of Petroleum Geologists, Tulsa, Oklahoma, p. 143–158.

1960: Studies of the western Canada Stingocephalinae; Journal of Paleontology, v. 34, p. 874–890.

Douglas, R.J.W., Gabrielse, H., Wheeler, J.O., Stott, D.F., and Belyea, H.R.

1970: Geology of Western Canada, Chapter VIII; *in* Geology and Economic Minerals of Canada, (ed.) R.J.W. Douglas; Geological Survey of Canada Report no. 1, p. 366–488.

Fowler, M.G. and Stasiuk, L.D.

1998a: Organic Geochemistry and Petrology; Chapter 5; *in* The Lower Paleozoic: A new frontier in the Western Canada Sedimentary Basin, Part 1, (ed.) G.S. Nowlan; Report to partners 1993-94, Geological Survey of Canada, Open File 3416.

1998b: Organic Geochemistry and Petrology; Chapter 5; *in* The Lower Paleozoic: A new frontier in the Western Canada Sedimentary Basin, Part 1, (ed.) G.S. Nowlan; Report to partners 1994-95, Geological Survey of Canada, Open File 3603.

Fuller, J.C.G.M. and Porter, J.W.

1969: Evaporites and carbonates: two Devonian basins of Western Canada; Bulletin of Canadian Petroleum Geology, v. 17, p. 182–193.

Fuzesy, L.M.

1980: Geology of the Deadwood (Cambrian), Meadow Lake and Winnipegosis (Devonian) Formations in west-Saskatchewan; Saskatchewan Department of Mineral Resources, Report 180, 64 p.

Grayston, L.D., Sherwin, D.F., and Allan, D.F.

1964: Middle Devonian, Chapter 5; *in* Geological History of Western Canada, (ed.) R.G. McCrossan and R.P. Glaister; Alberta Society of Petroleum Geologists, Calgary, Alberta, p. 49–59.

Hamilton, W.N.

1971: Salt in east-central Alberta; Research Council of Alberta, Bulletin 29.

Hein, F.J. and Nowlan, G.S.

1998: Regional sedimentology, conodont biostratigraphy and correlation of Middle Cambrian -Lower Ordovician(?) strata of the "Finnegan" and Deadwood formations, Alberta subsurface, Western Canada Sedimentary Basin; Bulletin of Canadian Petroleum Geology, v. 46, p. 166–188.

Holter, M.

1969: Geology of the Prairie Evaporite Formation of Saskatchewan; Saskatchewan Department of Mineral Resources, Report no. 123.

James, N.P. and Kendall, A.C.

1992: Chapter 14, Introduction to carbonate and evaporite facies models; *in* Facies Models, (ed.) R.G. Walker and N.P. James; Geological Association of Canada, p. 265–275.

Jin, J. and Bergman, K.M.
2000: Revised stratigraphy of the Middle Devonian (Givetian) Winnipegosis Carbonate–Prairie Evaporite Transition, Elk Point Group, southern Saskatchewan; Bulletin of Canadian Petroleum Geology, v. 49, p. 441–457.

Jin, J., Bergman, K., Haidl, F.M., Blair, M.J., and Reid, A.
1997: Vadose diagenesis of the Upper Winnipegosis Carbonate and the origin of the Ratner Laminite and Whitkow Anhydrite, Middle Devonian, southern Saskatchewan; Summary of Investigations 1997, Saskatchewan Geological Survey, *in* Saskatchewan Energy Mines Miscellaneous Report 97-4, p. 197–212.

Jones, L.J.
1965: The Middle Devonian Winnipegosis Formation of Saskatchewan; Saskatchewan Department of Mineral Resources, Report 98, 101 p.

Kendall, A.C.
1975: The Ashern, Winnipegosis and lower Prairie Evaporite Formations of the Commercial Potash Areas; *in* Summary of Investigations 1975 by the Geological Survey of Saskatchewan, (ed.) J.E. Christopher and R. Macdonald; Saskatchewan Department of Mineral Resources.

Kindle, E.M.
1914: The Silurian and Devonian section of western Manitoba; Geological Survey of Canada, Summary Report 1912, p. 247–261.

Klingspor, A.M.
1969: Middle Devonian Muskeg evaporites of western Canada; American Association of Petroleum Geologists, Bulletin, v. 53, p. 927–948.

Law, J.
1955: Geology of northwestern Alberta and adjacent areas; American Association of Petroleum Geologists, Bulletin, v. 39, p. 1927–1975.

Lobdell, F.K.
1984: Age and depositional history of the Middle Devonian Ashern Formation in the Williston Basin, Saskatchewan and North Dakota; *in* Oil and Gas in Saskatchewan, (ed.) J.A. Lorsong and M.A. Wilson; Saskatchewan Geological Society Special Publication 7, p. 5–12.

Maiklem, W.R.
1971: Evaporite drawdown - a mechanism for waterlevel lowering and diagenesis in the Elk Point Basin; Bulletin of Canadian Petroleum Geology, v. 19, p. 485–503.

Martindale, W. and MacDonald, R.W.
1989: Sedimentology and diagenesis of the Winnipegosis Formation (Middle Devonian), Tableland area, southwestern Saskatchewan; *in* Geology and Reservoir Heterogeneity, 1989 Core Conference; Canadian Society of Petroleum Geologists, Calgary, Alberta, p. 2–52.

McGehee, J.R.
1949: Pre-Waterways Paleozoic stratigraphy of Alberta Plains; American Association of Petroleum Geologists, Bulletin, v. 33, p. 604–613. Republished with revisions, 1954, Western Canada Sedimentary Basin; American Association of Petroleum Geologists, p. 131–142.

Meijer Drees, N.C.
1985: The Prairie Evaporite salt beds in the Lloydminster area of Saskatchewan and their potential for storage of radioactive material; Atomic Energy of Canada Ltd., Technical Record 269.

1986: Evaporitic deposits of Western Canada; Geological Survey of Canada, Paper 85-20.

1994: Elk Point Group in the Western Canada Sedimentary Basin, Chapter 10; *in* Geological Atlas of the Western Canada Sedimentary Basin, (comp.) G.D. Mossop and I. Shetsen; Canadian Society of Petroleum Geologists, Calgary, p. 129–147.

Meijer Drees, N.C., Palmer, B.C., Fowler, M.G., Stasiuk, L.D., Nowlan, G.S., and McGregor, D.C.
1995: Petroleum Geology of the Middle Devonian carbonates and evaporites in east-central Alberta; *in* The Economic Integration of Geology and Formation Evaluation, C.S.P.G. C.W.L.S. 1995 Core Session; (comp.) B. Cheadle, S. Leggitt, H. Raddysh, K. White, and C. Yeo; Canadian Society of Petroleum Geologists, Calgary.

Moore, P.F.
1988: Devonian geohistory of the western interior of Canada; *in* Devonian of the World, (ed.) N.J. McMillan, A.F. Embry, and D.J. Glass; Canadian Society of Petroleum Geologists, Memoir 14, v. I, p. 67–83.

1989: The Lower Kaskaskia sequence - Devonian; *in* Western Canada Sedimentary Basin: A Case History, (ed.) B.D. Ricketts; Canadian Society of Petroleum Geologists, p. 139–164.

1993: Devonian, Subchapter 4D; *in* Geology of Canada, no. 5, Sedimentary Cover of the Craton in Canada, (ed.) D.F. Stott and J.D. Aitken; Geological Survey of Canada, Ottawa, p. 150–199.

Norford, B.S., Haidl, F.M., Bezys, R.K., Cecile, M.P., McCabe, H.R., and Paterson, D.F.
1994: Middle Ordovician to Lower Devonian strata of the Western Sedimentary Basin, Chapter 9; *in* Geological Atlas of Western Canada Sedimentary Basin, (comp.) G.D. Mossop and I. Shetsen; Canadian Society of Petroleum Geologists, Calgary.

Norris, A.W.
1963: Devonian stratigraphy of northeastern Alberta and northwestern Saskatchewan; Geological Survey of Canada Memoir 313.

Norris, A.W., Uyeno, T.T., and McCabe, H.R.
1982: Devonian rocks of the Lake Winnipegosis - Lake Manitoba outcrop belt, Manitoba; Geological Survey of Canada, Memoir 392, and Manitoba Mineral Resources, Publication 77-1.

Nowlan, G.S.
1998a: The lower Paleozoic: A new frontier in the Western Canada Sedimentary Basin, Part 1, report to partners 1993–94; Geological Survey of Canada, Open File 3416.

1998b: The lower Paleozoic: A new frontier in the Western Canada Sedimentary Basin, Part 2, report to partners 1994–1995; Geological Survey of Canada, Open File 3603.

Paterson, D.F.
1973: Computer plotted isopach and structure maps of the Devonian Formations in Saskatchewan; Saskatchewan Department of Mineral Resources, Report 164, 15 p.

Perrin, N.A.
1982: Environments of deposition and diagenesis of the Winnipegosis Formation (Middle Devonian), Williston Basin, North Dakota; *in* Fourth Williston Basin Symposium, (ed.) J.E. Christopher and J. Kaldi; Saskatchewan Geological Society, Special Publication, v. 6, p. 51–66.

Porter, J.W. and Fuller, J.G.C.M.
1959: Lower Paleozoic rocks of northern Williston Basin and adjacent areas; American Association of Petroleum Geologists, Bulletin, v. 43, p. 124–189.

1964: Ordovician-Silurian, Chapter 4, Part I; *in* Geological History of Western Canada, (ed.) R.G. McCrossan and R.P. Glaister; Alberta Society of Petroleum Geologists, Calgary, p. 34–42.

Reinson, G.E. and Wardlaw, N.C.
1972: Nomenclature and stratigraphic relationships, Winnipegosis and Prairie Evaporite formations, central Saskatchewan; Bulletin of Canadian Petroleum Geology, v. 20, p. 301–320.

Richardson, J.B. and McGregor, D.C.
1986: Silurian and Devonian spore zones of the Old Red Sandstone Continent and adjacent regions; Geological Survey of Canada, Bulletin 364.

Sandberg, C.A. and Hammond, C.R.
1958: Devonian System in Williston Basin and central Montana; American Association of Petroleum Geologists, Bulletin, v. 42, p. 2293–2334.

Sarg, J.F.
1988: Carbonate sequence stratigraphy; *in* Sea Level Changes: An Integrated Approach, (ed.) C.K. Wilgus et al.; Society of Economic Paleontologists and Mineralogists, Special Publication 42, p. 155–182.

Shearman, D.J. and Fuller, J.G.
1969: Anhydrite diagenesis, calcitization and organic laminites, Winnipegosis Formation, Middle Devonian, Saskatchewan; Bulletin of Canadian Petroleum Geology, v. 17, p. 496–525.

Sherwin, D.F.
1962: Lower Elk Point section in east-central Alberta; Alberta Society of Petroleum Geologists, Journal v. 10, p. 185–191.

Stasiuk, L.D.
1999: Microscopic studies of sedimentary organic matter: Key to understanding organic-rich strata, with Paleozoic examples from Western Canada Basin; Geoscience Canada, v. 26, p. 149–172.

Streeton, E.G.
1971: The Middle Devonian Winnipegosis Formation of west-central Saskatchewan; M.Sc. thesis, University of Saskatchewan.

Tyrrell, J.B.
1892 Report on northwestern Manitoba with portions of the adjacent districts of Assiniboia and Saskatchewan; Geological Survey of Canada, Annual Report 1890-91, Part E.

Van Wagoner, J.C., Posamentier, H.W., Mitchum, R.M., Vail, P.R., Sarg, J.F., Loutit, T.S., and Hardenbol, J.
1988: An overview of the fundamentals of sequence stratigraphy and key definitions; *in* Sea Level Changes: An Integrated Approach, (ed.) C.K. Wilgus et al.; Society of Economic Paleontologists and Mineralogists, Special Publication 42, p. 39–46.

van Hees, H.
1956: Elk Point Group; Alberta Society of Petroleum Geologists, Journal, v. 4, p. 29–37.

1958: The Meadow Lake Escarpment - its regional significance to Lower Paleozoic stratigraphy; North Dakota Geological Society and Saskatchewan Geological Society, 2nd International Williston Basin Symposium, p. 70–78.

van Hees, H. and North, F.K.
1964: Cambrian, Chapter 3; *in* Geological History of Western Canada, (ed.) R.G. McCrossan and R.P. Glaister; Alberta Society of Petroleum Geologists, Calgary, p. 20–33.

Walker, C.T.
1957: Correlations of Middle Devonian rocks in western Saskatchewan; Saskatchewan Department of Mineral Resources, Report no. 25.

Wardlaw, N.C. and Reinson, G.E.
1971: Carbonate and evaporite deposition and diagenesis, Middle Devonian Winnipegosis and Prairie Evaporite formations of south-central Saskatchewan; American Association of Petroleum Geologists, Bulletin, v. 55, p. 1759–1786.

Williams, G.K.
1984: Some musings on the Devonian Elk Point Basin, Alberta; Bulletin of Canadian Petroleum Geology, v. 32, p. 216–232.

PLATES

Plate 1. Core samples of Ashern and Winnipegosis formations

a. Rubble conglomerate overlain by dolostone and carbonaceous shale (TOC 1.15%). Conglomerate is composed of fragments of very fine- to fine-crystalline, poorly porous and locally fossiliferous dolostone and a matrix of dark greyish green, silty and shaly dolostone. The lithology of the fragments is similar to that of the underlying Ordovician Red River Formation. The rubble is overlain by greyish green, silty, shaly, and pyritic dolostone. At the top is a dark grey, silty and pyritic shale including dolostone granules and grains. Ashern Formation, Strome 11-16-44-16W4; 1761.45 m (GSC photo no. 4413-29).

b. Two greenish grey and greyish brown mottled, silty and argillaceous, nodular limestone beds are separated from each other by a scoured surface overlain by a very coarse-grained crinoidal packstone, including sediment-filled brachiopods. Ashern Formation, Killam North 16-10-46-13W4; 1619.3 m (GSC photo no. 4270-6).

c. Brown crinoidal and brachiopodal limestone, wavy-interbedded with dark grey marlstone (TOC 1.75%). Cutknife Member, Winnipegosis Formation, Carruthers 10-11-45-23W3; 119 m (3904.5 ft.) (GSC photo no. 4413-52).

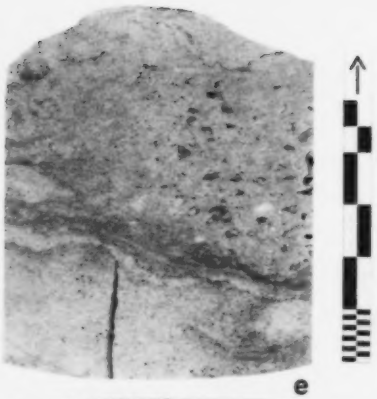
d. Porous, light greyish brown dolostone of massive, bioturbated aspect, includes dark grey, carbonaceous shale partings (TOC 2.22–46.43%). Cutknife Member, Poundmaker 12-28-45-22W3; 110.02 m (3636 ft.) (GSC photo no. 4413-14).

e. Light brown, very fine- to fine-crystalline dolostone. The lower bed has a fine- to coarse-fragmental packstone aspect. The upper bed has a fossiliferous, rudstone aspect and includes recrystallized amphiporids. The vuggy, interfossil and fracture porosity is cemented by halite. Cutknife Member, Eyehill 13-36-35-2W4; 161.3 m (5292 ft.) (GSC photo no. 4413-15).

f. Brown, fossiliferous limestone interbedded with dark grey carbonaceous layers (TOC 5.08%). Fragments of amphiporids and bulbous stromatoporoids occur in the lower part. Large fragments of platy and domal stromatoporoids in near-growth position are present in the upper part. The domal stromatoporoid is cut by a cavity filled with light grey, silty, geopetal sediment and semitranslucent halite. Needle-like anhydrite crystals are present. Fractures cemented by calcite extend downward from the base of the cavity. Cutknife Member, Killam North 16-10-46-13W4; 1610.5 m (GSC photo no. 4413-38).

g. Brown, anhydritic dolostone bed with peloidal pack- to grainstone aspect, is overlain by fragments of crustaceans and charophyte oogonia. Overlying, light brown, silty dolostone consists of mudstone and fine-grained packstone. Hopper-like halite crystals and scattered charophyte oogonia are present. Several desiccated surfaces are overlain by layers rich in mudclasts. Bawif Member, Killam North 16-10-46-13W4; 1596.5 m (GSC photo no. 4413-8).

g



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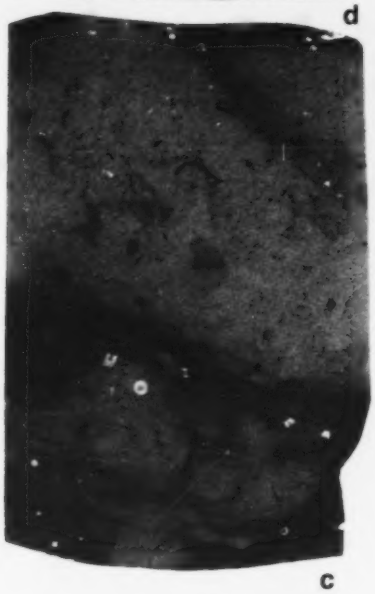

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a

Plate 2. Core samples of Winnipegosis and Prairie formations

a. Dark grey, silty and carbonaceous marlstone (TOC 4.99%) including fragments of stromatoporoids. Most fragments are dark on top, others are dark below, suggesting that some are in growth position and others not. Cutknife Member, Killam North 16-10-46-13W4, 1612.5 m (GSC photo no. 4412-24).

b. Light brown and pale greenish grey mottled, anhydritic, microcrystalline dolostone, including grey, irregularly shaped anhydrite nodules that form a mosaic. The dolomitic matrix includes nodular lenses of fine-peloidal aspect that contain mudclasts. Shell Lake Member, Carruthers 10-11-45-23-W3; 1155.95 m (3792.5 ft.) (GSC photo no. 4413-48).

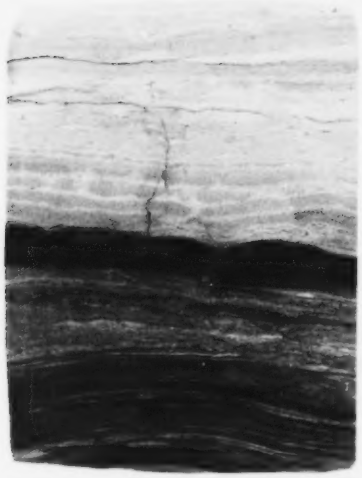
c. The lower part of the sample is a brown mottled, very fine-crystalline and vuggy dolostone. Some vugs represent recrystallized spongy stromatoporoids; others are leached brachiopods filled with laminated silty sediment or lined with sediment and cemented by halite. The dolostone is overlain by a white dolomitic layer that resembles a mud-cracked crust. The crust is erosionally overlain by a grey, fine-crystalline, peloidal dolostone and includes fenestral vugs filled with anhydrite or halite. It is overlain by a fine peloidal grainstone that has a laminar fenestral aspect. This bed is truncated at the very top of the sample by a second erosional surface. Cutknife Member, Killam North 16-10-46-13W4; 1609.25 m (GSC photo no. 4413-25).

d. Erosional contact between the Killam Member (below) and the Eyot Formation (above). The Killam Member is a light grey, silty, micro- to very fine-crystalline dolostone that includes leached fossil fragments (mostly charophyte oogonia) partly cemented by calcite. The Eyot Formation is a greyish green, dolomitic siltstone and contains elongate pebbles and coarse, subangular grains derived from the underlying dolostone bed. Chisholm 10-5-68-2W5; 1789.93 m (5872.5 ft.) (GSC photo no. 4444-19).

e. Light grey and brown mottled dolostone, including deformed, sediment-filled or anhydrite-cemented borings is erosionally overlain by greyish green, dolomitic shale containing many light grey inclusions composed of quartz silt and medium to coarse grains of dolostone. Killam Member, Venice 10-12-66-15W4, 1146.81 m (3762.5 ft.) (GSC photo no. 4444-16).

f. Interbedded, very fine crystalline dolostone, nodular-mosaic anhydrite and dark grey, carbonaceous shale. The dolostone has a peloidal aspect and includes fenestral vugs and deformed, burrow-like vugs filled with pyritic mudstone or cemented by anhydrite. Charophyte oogonia are present in the lower part of the sample above the dark greyish brown anhydrite. Several crust-like surfaces are present, some overlain by a bituminous shale (TOC 5.9–8.4%) Killam Member, Bruce 8-2-46-14W4; 1607.75 m (GSC photo no. 4413-34).

g. Stromatolitic structure composed of interlaminated, light brown dolomite, light grey anhydrite and dark grey bitumen is erosionally overlain by an irregularly layered interval composed of peloids, intraclasts, and charophyte oogonia. Interval is overlain by a black, anhydritic and bituminous shale bed. The upper part of the sample is a light brown, microcrystalline, anhydritic and peloidal dolostone. Bawif Member, Provost 6-4-37-16W4; 2006.12 m (GSC photo no. 4247-30).



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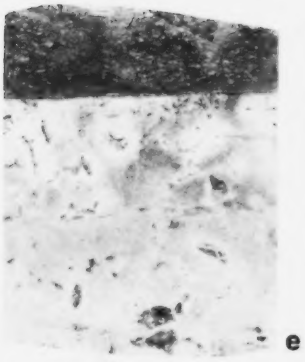

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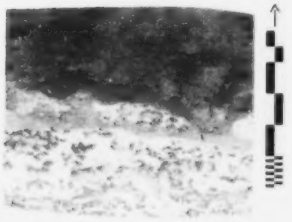

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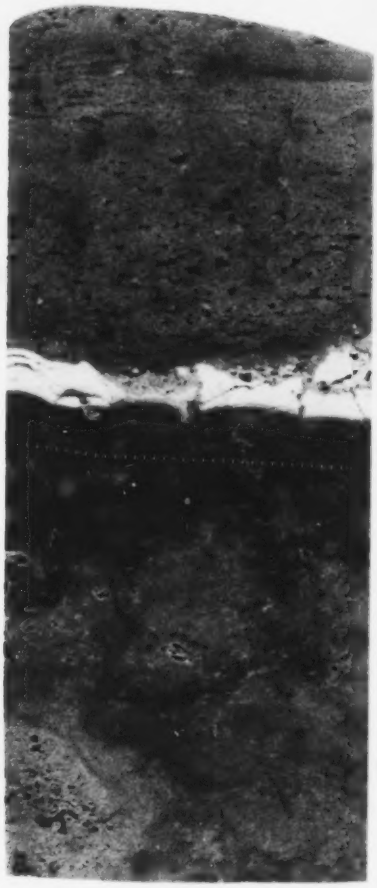

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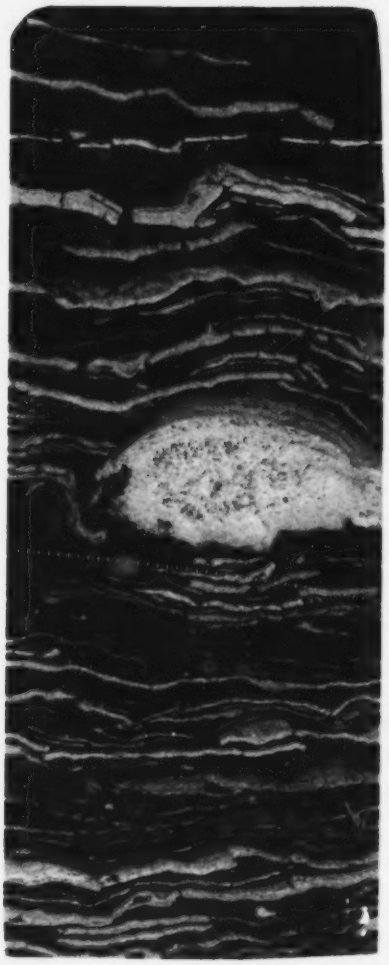

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Plate 3. Palynomorphs from the Ashern and Winnipegosis formations. Magnifications x660 unless otherwise indicated

1. *Rhabdosporites langii* (Eisenack) Richardson; GSC loc. C-245073, Provost 11-35-38-10W4, 1672 m, GSC 117365.

2. *Rhabdosporites vermiculatus* Sanders; GSC loc. C-245046, Spiers 11-15-34-15W4, 1914.75 m, GSC 117366.

3. *Archaeozonotriletes meandricus* Allen; GSC loc. C-245073, Provost 11-35-38-10W4, 1672 m, GSC 117367.

4. *Geminospora lemurata* Allen; GSC loc. C-245073, Provost 11-35-38-10W4, 1672 m, GSC 117368.

5. *Grandispora inculta* Allen; GSC loc. C-245073, Provost 11-35-38-10W4, 1672 m, GSC 117369.

6. *Hystricosporites porrectus* (Balme and Hassell) Allen, x430; GSC loc. C-245046, Spiers 11-15-34-15W4, 1914.75 m, GSC 117370.

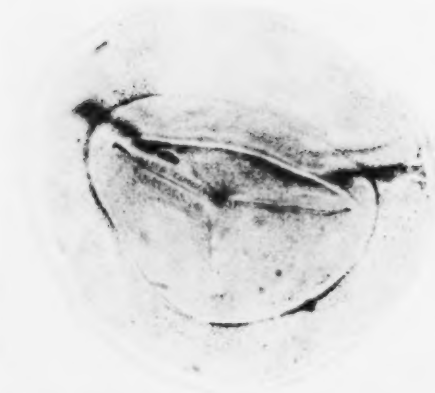
7. *Grandispora variospinosa* McGregor and Camfield; GSC loc. C-245073, Provost 11-35-38-10W4, 1672 m, GSC 117371.

8. *Acinosporites acanthomammillatus* Richardson; GSC loc. C-245046, Spiers 11-15-34-15W4, 1914.75 m, GSC 117372.

9. *Perotrilites selectus* (Arkhangelskaya) McGregor and Camfield; GSC loc. C-245073, Provost 11-35-38-10W4, 1672 m, GSC 117373.

10. *Retusotriletes rugulatus* Riegel; GSC loc. C-245046, Spiers 11-15-34-15W4, 1914.75 m, GSC 117374.

11,12. *Gloeocapsomorpha prisca* Zalessky; GSC loc. C-244014, Ardrossan 8-17-53-21W4, 6174.1 ft., GSC 117375 and GSC 117376.



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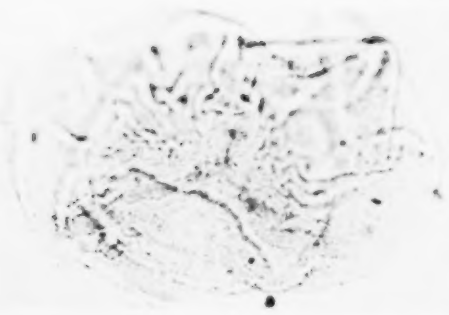

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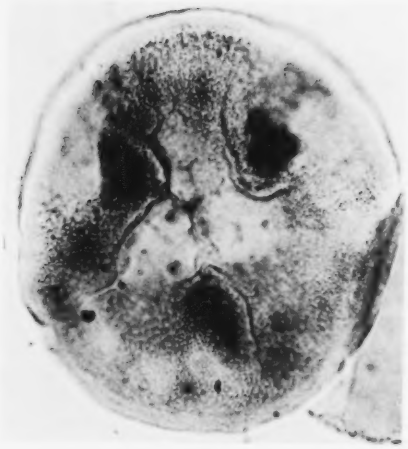

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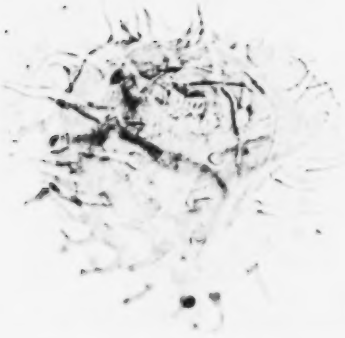

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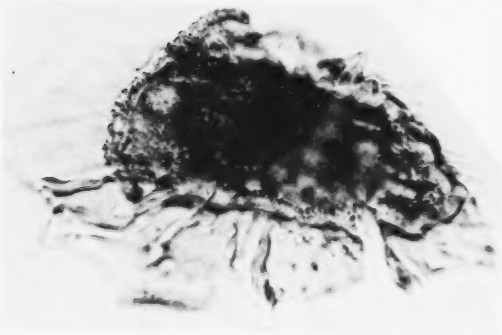

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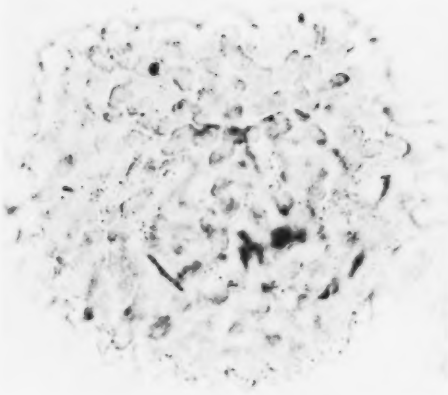

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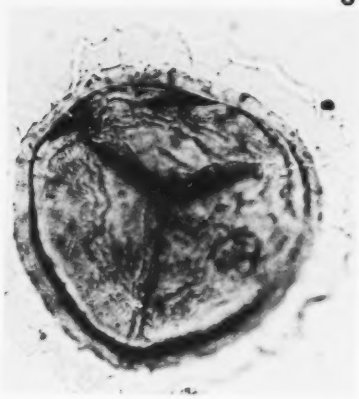

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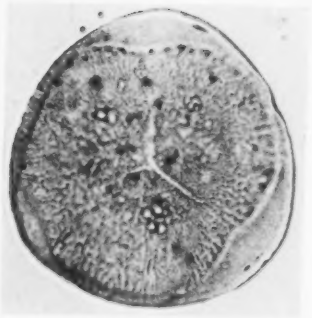

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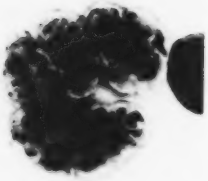

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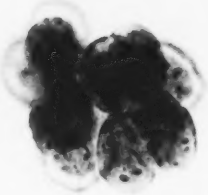

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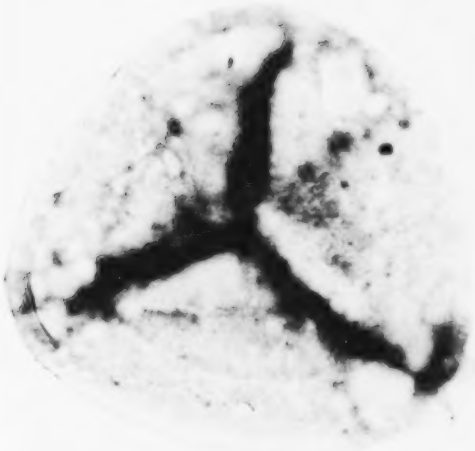
Plate 4. Spores from the Eyot Formation. Magnifications x800 unless otherwise indicated

1. *Contagisporites optivus* (Chibrikova) Owens var. *optivus*, x525; GSC loc. C-245290, Bashaw 16-36-41-23W4, 2274.9 m, GSC 117377.
2. *Emphanisporites*? sp.; GSC loc. C-245314, Tomahawk 16-18-52-5W5, 8584.33 ft., GSC 117378.
3. *Costazonotriletes*? sp.; GSC loc. C-245286, Bashaw 16-36-41-23W4, 2273.34 m, GSC 117379.
4. *Aneurospora goensis* Streel; GSC loc. C-245310, Tomahawk 16-18-52-5W5, 8578 ft., GSC 117380.
5. *Emphanisporites*? sp.; GSC loc. C-245310, Tomahawk 16-18-52-5W5, 8578 ft., GSC 117381.
6. *Archaeozonotriletes variabilis* Naumova; GSC loc. C-245286, Bashaw 16-36-41-23W4, 2273.58 m, GSC 117382.
7. *Perotrilites ergatus* Allen; GSC loc. C-245286, Bashaw 16-36-41-23W4, 2273.34 m, GSC 117383.
8. *Chelinospora concinna* Allen; GSC loc. C-245314, Tomahawk 16-18-52-5W5, 8584.33 ft., GSC 117384.
9. *Kraeuselisporites violabilis* (Chibrikova) Turnau; GSC loc. C-245317, Tomahawk 16-18-52-5W5, 8572.58 ft., GSC 117385.
10. *Cristatisporites triangulatus* (Allen) McGregor and Camfield; GSC loc. C-245310, Tomahawk 16-18-52-5W5, 8578 ft., GSC 117386.
11. *Costazonotriletes* sp.; GSC loc. C-245303, Tomahawk 16-18-52-5W5, 8569.75 ft., GSC 117375 and GSC 117387.



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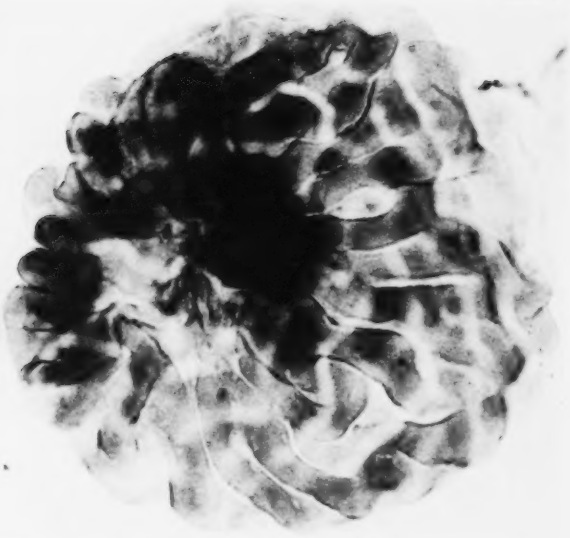

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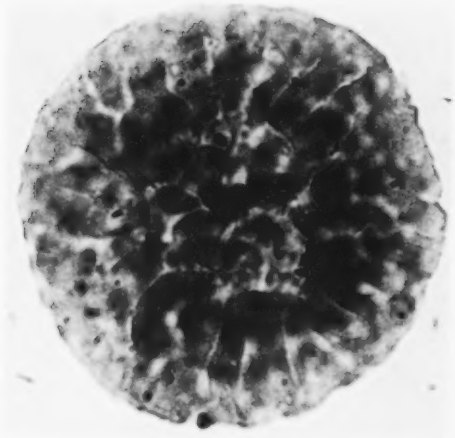

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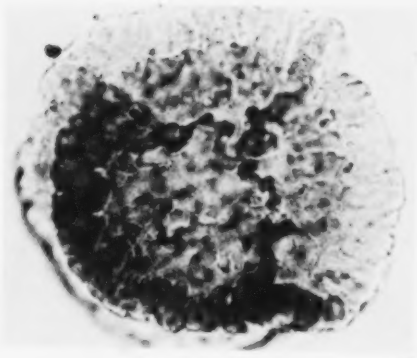

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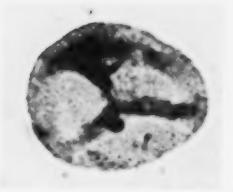

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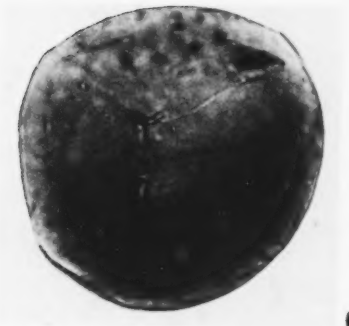

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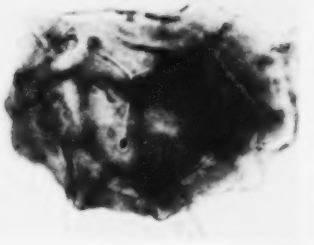

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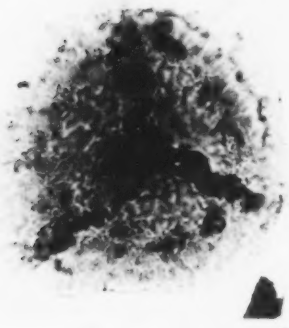

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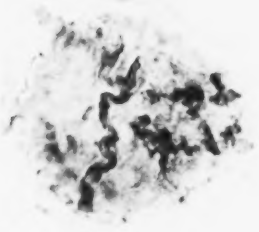

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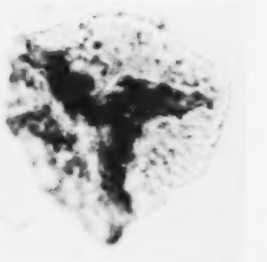

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